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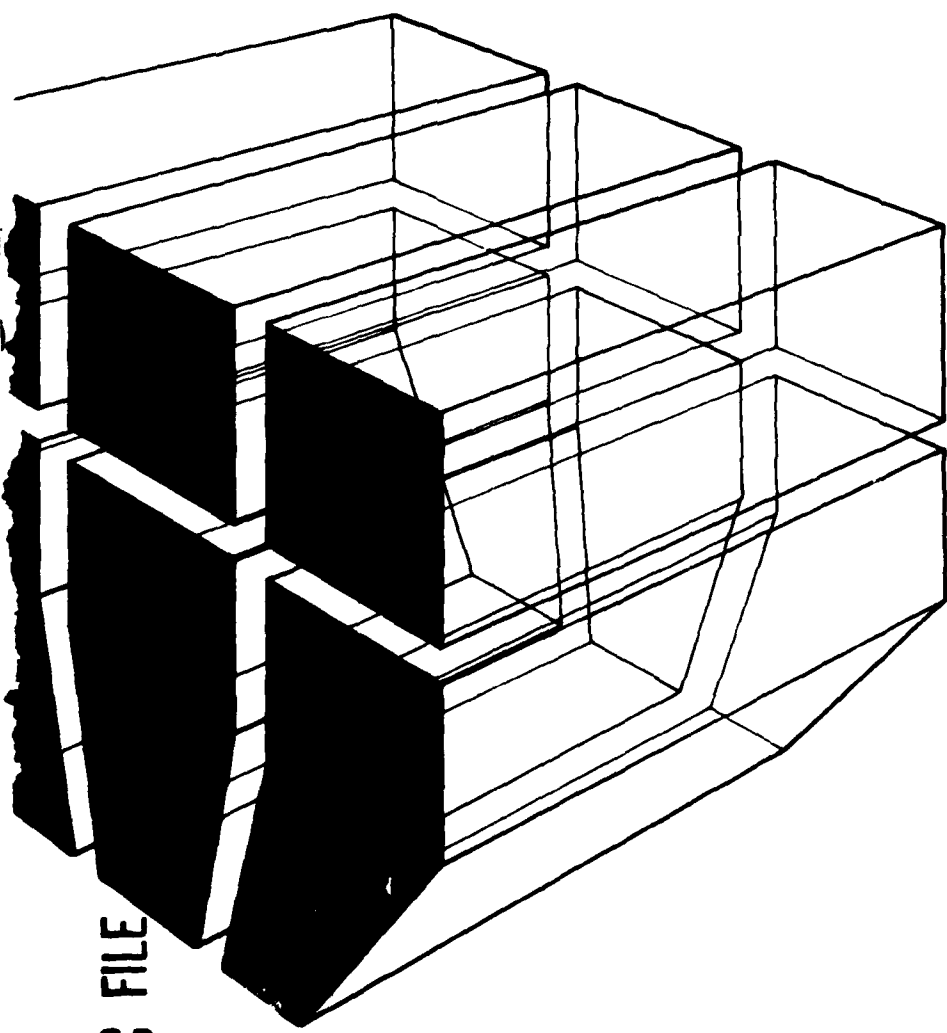construction
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TECHNICAL REPORT E-175
APRIL 1982

DEVELOPMENT AND ANALYSIS OF ENERGY
CONSUMPTION NORMS FOR FAMILY HOUSING

by
L. M. Windingland
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Congress has directed in PL 95-82 and PL 95-101 that ceilings be
established for energy consumption in military housing, and that a method
be developed for assessing actual energy consumption above the ceiling.
This report describes and analyzes a procedure used to set energy consump-
tion ceilings (norms) for military family housing during a 1-year test
program.

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Block 20 continued.

The report includes the methods used to group thermodynamically equivalent buildings. These building groups are used to provide statistical samples for analysis of the norm and the range, mean and standard deviation of actual consumption.

The weather parameters used in the norm algorithm properly predict the trends in heating and cooling requirements of residential buildings. Variations between the calculated norm and actual consumption are illustrated, and explained. The report also shows how family living habits cause actual utility consumption to vary widely among housing units that are thermodynamically alike. This report concludes that an equitable energy use ceiling for military family housing can be established, but that the present norm concepts and algorithms need to be refined.

FOREWORD

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DEVELOPMENT AND ANALYSIS OF
FAMILY HOUSING NORMS

1 INTRODUCTION

Background

To obtain widespread energy conservation in Department of Defense (DOD) family housing units, Congress proposed that DOD meter energy consumption in the units and charge occupants for energy consumption based on these meter readings (PL 95-82 and PL 95-101).[1] However, since free utilities are part of the total compensation package for military personnel in military housing units, Congress decided that the billing should only be made for energy in excess of that consumed with good conservation practices. Therefore, each housing unit was to be assigned a norm for energy usage. Occupants were to be charged only for consumption beyond this norm, which was to be established so that it could be met by a family using good energy conservation practices. Thus, the goal of encouraging energy conservation without disrupting the military pay/compensation package would be achieved.

The U.S. Army Construction Engineering Research Laboratory (CERL) was assigned the task of developing the procedure for calculating energy-use norms for family housing units. The Energy-Use Norm (EUN) for the family housing unit was to reflect the actual construction of the housing unit, its operation and occupancy, and the weather conditions during the billing period. Congress required that the EUN be developed using state-of-the-art energy analysis computer programs.

To begin this program, Congress established a 1-year demonstration to test the feasibility of family housing metering, and required that the demonstration include not fewer than 10,000 family housing units in the four military services. During the demonstration program, mock bills were to be developed for each of the housing units, but the occupants were not to be required to pay for energy use in excess of their norm. This report documents the completion of the 1-year demonstration and evaluation.

Objective

The objectives of this study were to develop a procedure for establishing energy consumption norms for family housing units, analyze the adequacy of the norms during the 1-year energy consumption demonstration, and determine areas where the norm could be refined, if necessary, to produce an accurate system to charge military occupants for excessive energy use.

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[1] Public Law 95-82, _Military Construction Authorization Act, 1978_ (August 1, 1977); Public Law 95-101, _Military Construction Appropriation Act, 1978_ (August 15, 1977).

Approach

To meet the objectives of this study, CERL:

1. Developed for family housing units a procedure for calculating EUNs which implements DOD guidance for good energy conservation practices.

2. Defined the data required from family housing units in order to be able to calculate an EUN for that unit.

3. Developed a survey form from which the required data could be obtained from family housing units and trained survey teams from each of the military services to collect the data.

4. Developed algorithms (based on the data from the buildings surveyed and the use of the Building Loads Analysis and System Thermodynamics [BLAST] energy analysis program) for use in the billing routine to calculate the EUNs.[2]

5. Obtained actual consumption and norm data during the demonstration program to form a basis for analysis.

6. Analyzed and evaluated demonstration data and, if deficient, determined areas where norms could be refined.

Outline of Report

Chapter 2 describes the development of the EUN algorithm, provides a description of the energy conservation specifications used to achieve the EUN, and shows the step-by-step procedures used in calculating the norm. Chapter 3 describes the procedures used in surveying the family housing units and the methods used to develop coefficients for the norm algorithms. Chapter 4 describes the analysis of the 1-year test data and includes curves showing the values of norm and actual consumption for numerous samples of military housing units. Chapter 5 presents conclusions.

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[2] D. C. Hittle, The Building Loads Analysis and System Thermodynamics (BLAST) Program, Version 2.0, Users Manual, Vols I and II, Technical Report (TR) E-153/ADA072272 and ADA0722730; The Building Loads Analysis and System Thermodynamics (BLAST) Program Input Booklet, TR E-154/ADA072435 (U.S. Army Construction Engineering Research Laboratory [CERL], June 1979).

2 DEVELOPMENT OF PROCEDURE FOR CALCULATING ENERGY USE NORM

Specifications

The first step in establishing an EUN was to break a housing unit's energy consumption into various components (such as heating, cooling, cooking, and hot water), and to establish the DOD criteria for good energy conservation practice in each of these areas. The energy use categories and the criteria for good energy conservation practice were set by DOD before CERL began its work.[3] These categories are:

1. Electrical energy to run all electrical loads except heating and cooling. This category includes energy consumption for lights, wall outlets, and any other electrical loads. The DOD criteria for good energy conservation practice are based on the month and on the number ot bedrooms in the housing unit. For one- and two-bedroom units, the criteria, given as a monthly kilowatt hour allotment, are shown in Table 1. For three-, four-, and five-bedroom units, the kwh allotment is shown in Table 2.

2. Energy for cooking. The DOD criteria are based on the number of bedrooms in the housing units and the fuel type. For one- and two-bedroom units, the allotment is .246 therms (24,600 Btu or 2.6×10^7 J) per day if gas is used, and 2.88 kwh (1.04×10^7 J) per day if electricity is used. For three-, four-, and five-bedroom units, the allotment is 0.274 therms (27,400 Btu or 2.89×10^7 J) per day for gas cooking and 3.22 kwh (1.16×10^7 J) per day for electric cooking.

3. Energy to run pilot lights used for heating, cooking, and hot water appliances. The DOD-specified criterion is an allotment based on the number of pilot lights on each type of appliance in a housing unit. The average values of energy consumptions of the various appliances' pilot lights were determined by CERL.

4. Energy for heating domestic hot water. The DOD criterion is the energy required to heat 25 gallons (94.6 L) of hot water per person per day to 140°F (60°C) from the cold water supply temperature for the installation.

5. Energy for space heating. CERL was assigned the responsibility of developing a procedure which would establish an allotment for space heating that considered the actual weather conditions during the billing period and the construction and operation of the housing unit. The heating energy norm was both to allow for the internal loads generated by 1 through 4, above, and to reflect an internal housing unit temperature thermostat setting of 68°F (20°C).

6. Energy consumption for space cooling. As with space heating, CERL was to develop a procedure which would establish a space cooling energy

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[3] Office of the Assistant Secretary of Defense Letter, Subject: "Testing of Military Utility Consumption of Military Family Housing Occupants -- Establishment of Norms" (2 November 1977).

Table 1

Allotted Electrical Energy Consumption (Non-Heating and -Cooling) for One- and Two-Bedroom Housing Units

Month	Electrical Load	
	kwh	GJ
January	489	1.76
February	477	1.71
March	464	1.67
April	466	1.67
May	469	1.68
June	472	1.69
July	475	1.71
August	477	1.71
September	479	1.72
October	482	1.73
November	484	1.74
December	487	1.75

Table 2

Alloted Electrical Energy Consumption (Non-Heating and -Cooling) for Three-, Four-, and Five-Bedroom Housing Units

Month	Electrical Load	
	kwh	GJ
January	698	2.51
February	681	2.45
March	664	2.39
April	667	2.40
May	671	2.41
June	674	2.42
July	681	2.45
August	678	2.44
September	684	2.46
October	688	2.47
November	691	2.48
December	695	2.50

consumption norm that reflected actual weather conditions during the billing period, the internal loads generated by 1 through 5, above, and an internal housing unit temperature of 78°F (25.6°C).

7. Miscellaneous energy consumption. DOD specified that a category for miscellaneous energy consumption should be provided to cover such items as fans and pumps for heating and cooling systems, and any exterior lighting or energy consumption devices attached to the housing unit's metering system.

CERL developed the algorithms for calculating space heating and cooling norms based on the BLAST computer program. Because of both the great similarity between family housing units on military installations and the great cost of surveying and analyzing all 10,000 units in the demonstration program, a computer analysis of each unit was impractical. Instead, typical building types were analyzed with the BLAST program, which simulates a building's energy use. Then CERL developed a procedure generalizing the results to all buildings of that type with this procedure, the calculated heating and cooling loads accounted for those variations (among similar housing units) which would impact energy consumption.

Norm Development

The heating and cooling loads in family housing units are dependent on the interrelationship of many variables -- including outdoor air temperature; indoor thermostat setting; insulation levels in the walls, roof and floor; number of windows; rate of outdoor air leakage; amount and usage of lights and appliances; number of occupants; orientation; shading; and system efficiencies. The first step in producing a family housing heating and cooling norm was to learn how the energy consumption in a family housing unit reacted to changes in such climatic, construction, and operational parameters. Using the BLAST program, CERL analyzed these changes by varying each parameter over wide ranges to determine its effects on the consumption of heating or cooling energy.

To determine climatic effects on energy consumption, CERL chose 1-year hourly weather tapes from eight cities to represent a variety of climatic conditions. The weather sites chosen were Amarillo, TX, Atlanta, GA, Chicago, IL, Los Angeles, CA, Madison, WI, New Orleans, LA, Norfolk, VA, and Washington, DC. The number of heating degree days and number of hours that the dry-bulb temperature exceeded 78°F (25.6°C) were determined from the weather tapes for each month. These tapes were used to provide hourly weather data to the BLAST computer program during 1-year simulations of the family housing units.

Effects of different construction parameters on energy consumption were determined by describing typical housing units (single and multi-story) and by coding their geometries for input to the BLAST program. CERL selected wall, roof, and floor constructions which ranged from very low to very high insulation levels, and were of various construction densities. Using the coded information, the BLAST program simulated the housing unit's energy consumption for each weather tape and each type of construction, while holding all other variables constant. The monthly heating and cooling requirements for each type of construction (as provided by the BLAST program) at each climatic site were determined. Similarly, other variables -- such as indoor thermostat setting, infiltration rate, solar gain, and internal gains -- were studied to determine their effects on heating and cooling requirements. Figure 1 illustrates the effects (as determined with the BLAST program) of different thermostat settings on heating loads for a family housing unit.

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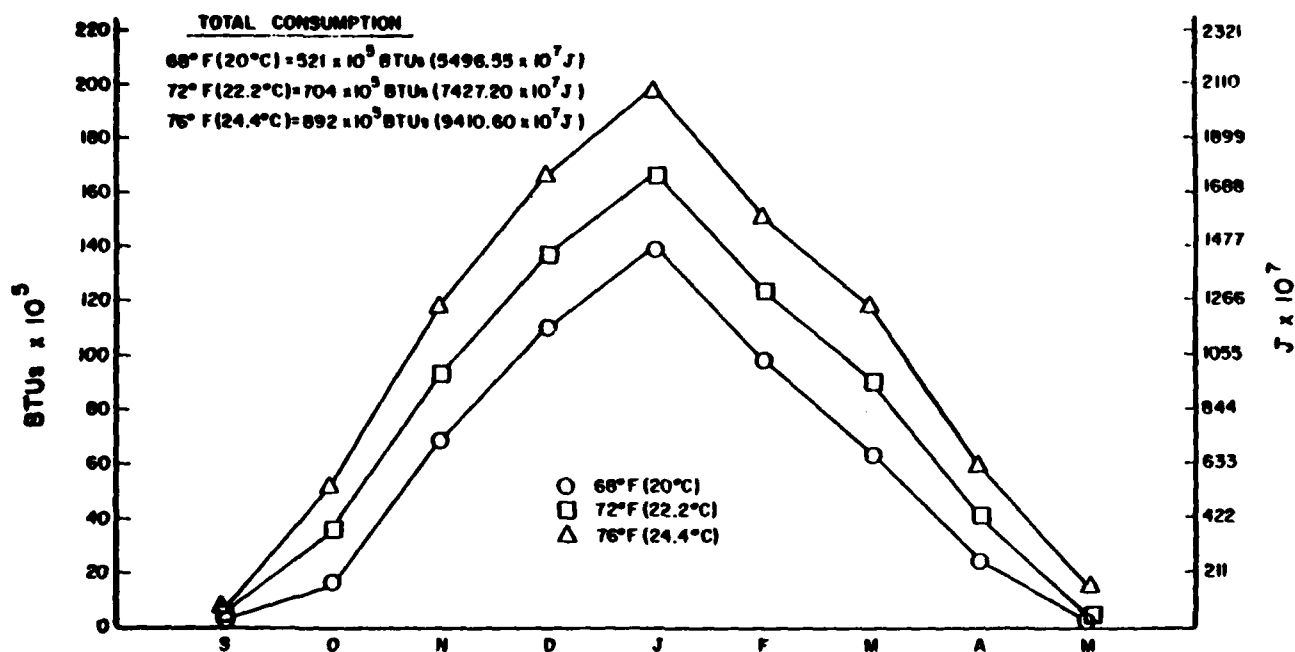
Figure 1. Heating load at various indoor thermostat settings.

The data obtained from the BLAST program simulations were then plotted so various effects could be observed. Equations that best modeled the data for heating and cooling were developed (Equations 8 and 9, p 18). The equations can be used to determine the energy requirement of a family housing unit -- provided the input data for the the units are available. The coefficients B1, B2, and B3 in the heating algorithm (Equation 8) are obtained from fitting the BLAST-simulated consumption (with energy conservation specifications) and weather data for a particular building to the equation by means of regression analyses. These coefficients establish the heating-energy use curve for a particular building (see categories of building groups, pp 11-13). The energy use for a particular building within that group can then be adjusted using the conduction/infiltration constant "A" for variations in the thermal conductivity of the unit, window area, and infiltration rates.

The heating consumption of a family housing unit is primarily a function of the overall thermodynamic characteristics ("U" value) of the building envelope, the rate of infiltration of outside air (combined in the norm calculation as the conductive/infiltration constant "A") and the indoor thermostat setting. Each of these parameters has a direct correlation with heating degree days (a function of the average outdoor temperature). Although the accuracy of Equation 8 tends to decrease at low (less than 100) heating degree days, it is accurate within 5 percent (based on the simulations) for months with significant heating requirements (more than 100 heating degree days).

The coefficients listed for the cooling algorithm are similar for all the housing units. As Equation 9 indicates, adjustments in energy use for

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different housing units are dependent on the conduction/infiltration constant "A," the infiltration into the unit, and the window area. The constant 10,650 represents the internal gain of the unit. Infiltration seems to appear twice in the equation; however, the coefficients have been manipulated algebraically, so that this repetition does not occur.

The cooling consumption of a family housing unit depends on the internal load (lights, equipment, and people), the solar gain through the windows, the heat gain through the walls, and the infiltration rate. For these building parameters, the cooling load per hour (when the outdoor temperature is above 78°F [25.6°C]), can be determined. It was assumed that a family housing occupant would use natural ventilation in the house when the outdoor temperatures are below 78°F (25.6°C) during the cooling season.

Method of Calculating Energy-Use Norms

As specified at the beginning of this chapter, the energy consumption (E) for a family housing unit is given by:

$$E = Elect + Pilot + DHW + Cook + Heat + Cool + Other \qquad [Eq 1]$$

where:

   Elect = energy to run all electrical loads except for
          heating and cooling

   Pilot = energy to run pilot lights for heating, cooking,
          and hot water appliances

   Cook = energy used for cooking

   DHW = energy used for heating domestic hot water

   Heat = energy used for space heating

   Cool = energy used for space cooling

   Other = miscellaneous energy consumers such as fans and pumps for
          heating and cooling distribution and exterior lighting
          or other electrical loads which are not part of the
          residences but are connected to the residence's meter.

The EUN is the value of energy consumption found in Equation 1 when the factors on the right-hand side of Equation 1 represent energy-conservative operation. Thus,

$$EUN = E + P + DHW + CK + EH + EC + EO \qquad [Eq 2]$$

where:

   E, P, CK, DHW, EH, EC, and EO are equal to the energy-conservative values of Elec, Pilot, Cook, DHW, Heat, Cool, and Other.

Since energy-conservative operation depends on the way occupants operate their housing unit, good energy conservation practice involves effecting existing policy rather than developing new technology. The energy-usage specification corresponding to good energy conservation practices, as defined by DOD, was given previously (pp 11-13). From the energy-conservation specification, a description of the housing unit and a computer analysis of selected family housing units, the procedure described below was developed for calculating a housing unit's energy-use norm with Equation 2. The billing algorithm is based on this procedure.

Step-by-Step Procedure for Calculating Energy-Use Norm

Step 1

Calculate the nonheating and cooling elecrical consumption (E). The energy norm for electrical consumption was expressed as:

$$E = \sum_{i=1}^{12} N_i \, E_i \qquad \text{[Eq 3]}$$

where:

N_i = number of days in billing period which fall in the ith month (i.e., i=1=January, i=2=February).

E_i = daily DOD-specified electrical energy consumption (kwh for other than heating and cooling for the ith month). The daily values for E_i are given in Table 3 and depend on the number of bedrooms in the housing unit.

Table 3

Daily Electrical Energy-Use Norms for Lighting and Appliances

Month	1-2 Bedroom		3-5 Bedroom	
	kwh/day	MJ/day	kwh/day	MJ/day
January	15.77	56.77	22.52	81.07
February	17.04	61.34	24.32	87.55
March	14.97	53.89	21.42	77.11
April	15.53	55.91	22.32	80.35
May	15.13	54.47	21.65	77.94
June	15.73	56.63	22.47	80.89
July	15.32	55.15	21.97	79.09
August	15.90	57.24	21.87	78.73
September	15.97	57.49	22.80	82.08
October	15.55	55.98	22.19	79.88
November	16.13	58.07	23.03	82.91
December	15.71	56.56	22.42	80.71

Step 2

Calculate the energy (P) to run gas and oil pilot lights.

$$P = N\,P_d \qquad\qquad [Eq\ 4]$$

$$N = \sum_{i=1}^{12} N_i \qquad\qquad [Eq\ 5]$$

where:

N = number of days in billing period

P_d = total daily consumption for all pilot lights

Daily consumption of pilot lights for individual pieces of equipment are given in Table 4.

Step 3

Calculate energy consumption for domestic hot water (DHW).

$$DHW = \frac{(140^\circ - T_{sw})\,8.34\,(25)\,(OCC)\,(N)}{EFF_{HW}} \qquad\qquad [Eq\ 6]$$

where:

N = number of days in billing period

T_{sw} = average temperature of supply water for billing period ($^\circ$F)

OCC = number of occupants in housing unit

EFF_{HW} = efficiency of hot water heater including losses from storage tank.

Table 4

Daily Pilot Light Energy-Use Norms

Equipment Type	Btu/day	MJ/day
Range Pilot	4100	4.32
Hot Water Heater Pilot	9600	10.12
Clothes Dryer Pilot	9600	10.12
Furnace Pilot	20,500	21.62
Air Conditioner Pilot	20,500	21.62

Note: For space heaters, use 9600

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Step 4

Calculate energy consumption for cooking (CK).

$$CK = N\ C_d \qquad\qquad [Eq\ 7]$$

where:

C_d = DOD-specified allowable daily energy consumption for cooking as given in Table 5. C_d depends on number of bedrooms and type of appliance.

Step 5

Calculate energy consumption for heating (EH).

$$EH = \frac{(N)(A)(B3)}{EFF_H}[HDD_d + (B1)]\ [1 - e^{-(B2)(HDD_d)}] \qquad [Eq\ 8]$$

$$HDD_d = HDD/N \qquad\qquad [Eq\ 9]$$

Table 5

Daily Cooking Energy-Use Norms

	1-2 Bedrooms	3-5 Bedrooms
Elect	2.88 kwh (10.37 MJ/day)	3.22 kwh (11.59 MJ/day)
Gas	24,600 Btu (25.95 MJ/day)	27,400 Btu (28.90 MJ/day)

where:

A, B1, B2, B3 = constants for housing unit which describe the construction of the building as found from surveys, BLAST, and regression analyses.

HDD_d = daily heating degree days

HDD = number of heating degree days in billing period

EFF_H = efficiency of heating system.

Step 6

Calculate energy consumption for cooling (EC).

$$EC = HR\ \frac{(C1)}{COP}\ [10.650 + 2.75(A) + .158\ (VOL) + 13.2\ (WA)] \qquad [Eq\ 10]$$

where:

> HR = number of hours in the billing period when the dry-bulb temperature exceeds 78° (25.6°C)
>
> Cl = coefficient of performance (COP) adjustment factor
>
> COP = seasonal coefficient of performance for the cooling system
>
> A = conduction/infiltration constant
>
> VOL = volume of housing unit
>
> WA = window area.

Step 7

Calculate other energy consumption (EO).

$$EO = PH \ (EH + EC) + EOUT \qquad\qquad \text{[Eq 11]}$$

where:

> PH = Electrical energy used by heating and cooling fan system per Btu (J) of system output
>
> EOUT = all energy loads outside the dwelling which are billed to the occupant.

Step 8

Calculate energy-use norms.

Using Equation 2, the results of steps 1 through 7 are summed by energy type (gas, oil, electrical) and converted to the appropriate billing units (e.g., therms, kwh, gallons of oil).

Billing Program

This step-by-step procedure, as well as a data base and data element description, were prepared for input to a computerized billing program. The flow chart for the step-by-step procedure outlined above is shown in Figure 2. But before this calculation procedure could be used, a data base was required for each housing unit. Table 6 shows this data base and the corresponding variables for the flowchart in Figure 2. Table 7 defines the inputs (primarily weather data) required to calculate a norm for a billing period.

Table 8 lists constant and output variables calculated in the norm procedure. The values for the arrays in Table 8 come from Table 3 [E(I,BED)] or are calculated from the input data [N(I)]. The values for the input data specified in Table 7 come from measurements made during each billing period by

the installation. The housing data base information listed in Table 6 comes from the family housing surveys and the data generated from BLAST analysis of selected family housing units. The survey procedure is described in Chapter 3.
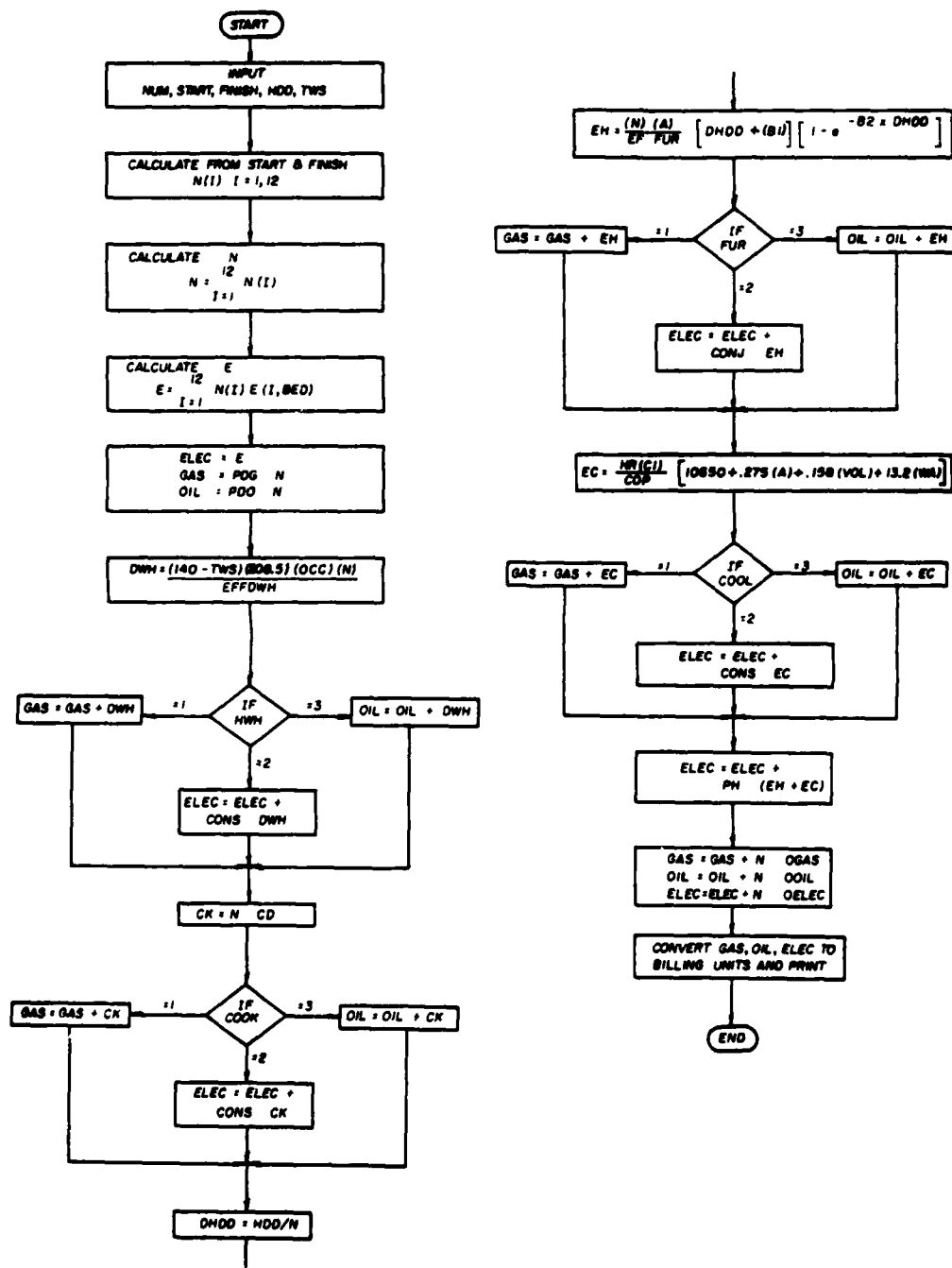
START

INPUT
NUM, START, FINISH, HDD, TWS

CALCULATE FROM START & FINISH
$N(I) \quad I = 1, 12$

CALCULATE N
$N = \sum_{I=1}^{12} N(I)$

CALCULATE E
$E = \sum_{I=1}^{12} N(I) E(I, BED)$

ELEC = E
GAS = POG N
OIL = POO N

$DWH = \dfrac{(140 - TWS)(8.5)(OCC)(N)}{EFFDWH}$

IF HWH
=1 → GAS = GAS + DWH
=3 → OIL = OIL + DWH
=2 → ELEC = ELEC + CONS DWH

CK = N CD

IF COOK
=1 → GAS = GAS + CK
=3 → OIL = OIL + CK
=2 → ELEC = ELEC + CONS CK

DHDD = HDD/N

$EH = \dfrac{(N)(A)}{EFF\ FUR} \left[DHDD + (BI) \right] \left[1 - e^{-.82 \times DHDD} \right]$

IF FUR
=1 → GAS = GAS + EH
=3 → OIL = OIL + EH
=2 → ELEC = ELEC + CONJ EH

$EC = \dfrac{HR(CLI)}{COP} \left[10850 + .275(A) + .198(VOL) + 13.2(WW) \right]$

IF COOL
=1 → GAS = GAS + EC
=3 → OIL = OIL + EC
=2 → ELEC = ELEC + CONS EC

ELEC = ELEC + PH (EH + EC)

GAS = GAS + N OGAS
OIL = OIL + N OOIL
ELEC = ELEC + N OELEC

CONVERT GAS, OIL, ELEC TO BILLING UNITS AND PRINT

END

Figure 2. Norm calculation procedure.

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Table 6

Data Base for Each Housing Unit

SITE   = Location
NUM   = Building number
BED   = Number of bedrooms   = 1,1 & 2 bedrooms
                                  = 2,3 - 5 bedrooms
OCC   = Number of occupants
HWH   = Type domestic hot water heat (gas = 1, elect = 2, oil = 3)
EFFDHW = Efficiency of domestic hot water heater
COOK   = Type of cooking appliance (gas = 1, elect = 2, oil = 3)
CD   = Daily allowable cooking energy (Btu)
A   = U-factor/infiltration constant
B1   = Building occupancy/internal load for heating calculation factor
B2   = Building mass factor for heating calculation
PDG   = Daily gas consumption for all gas pilots
PDO   = Daily oil consumption for all oil pilots
EFFUR   = Efficiency of heating system
FUR   = Type of furnace (gas = 1, elect = 2, oil = 3)
K   = Building cooling consumption factor
COP   = Coefficient of performance of cooling system
COOL   = Type of cooling system (gas = 1, elect = 2, oil = 3)
PH   = Electrical power consumed by heating/cooling system fan per
          Btu of heating or cooling
OGAS   = Daily gas consumption billed to occupant but external
          to dwelling
OOIL   = Daily oil consumption billed to occupant but external
          to dwelling
OELEC   = Daily electrical consumption billed to occupant
          but external to dwelling

Table 7

Input for Each Billing Period

NUM   = Building number
START   = First day of billing period
FINISH = Last day of billing period
HDD   = Heating degree days in billing period
TWS   = Avg. temp of water supply during billing period ($^{\circ}$F)
HR   = Number of hours in billing period dry-bulb temperature
          exceeds 78°F

Table 8

Arrays and Variables Used in EUN Flowchart

N(I)   = Number of days in billing period which fall in the Ith month
            (I=1=Jan, I=2=Feb, etc.).
E(I,BED)= Daily electrical energy-use norm for lights and appliances
            for I^{th} month as function of number of bedrooms.
            Values are obtained from Table 4 and stored in billing program.

Calculated Variables:

N   = Number of days in billing period
E   = Electrical consumption for lights and appliances (kwh)
ELEC   = Total electrical consumption for billing period (kwh)
GAS   = Total gas consumption for billing period (Btu)
OIL   = Total oil consumption for billing period (Btu)
CONS   = Conversion from Btu to kwh = 3.41297×10^3
DWH   = Energy used during billing period to heat domestic hot
            water (Btu)
CK   = Energy used during billing period for cooking (Btu)
DHDD   = Avg. daily heating degree day for billing period
EH   = Energy used for heating during billing period (Btu)
EC   = Energy used for cooling during billing period (Btu)

3 FAMILY HOUSING SURVEY PROCEDURE FOR DEMONSTRATION PROGRAM

To determine an energy consumption norm for a family housing unit, CERL had to obtain information about the housing unit's heat transfer properties, occupancy and operation, heating and cooling systems and any other energy-consuming devices associated with the dwelling. To collect this information, installations established survey teams; these groups examined the dwellings which were part of the family housing metering demonstration program.

The basis for setting the energy consumption norms was computer analysis of the housing unit using the BLAST energy analysis program. Since it was impractical -- because of the time, manpower, and money involved -- to make a BLAST analysis of all 10,000 family housing units, only selected units were analyzed with BLAST. But by using appropriate correction factors, results of the BLAST analysis of related housing units were generalized for all housing units, as described above. This simplifying use of BLAST can be justified for two reasons. First, many of the family housing units are in fact identical from an energy consumption standpoint since the DOD often uses standard designs and usually builds multiple versions of the same unit at any one location. Second, the effect on energy consumption of many variations in housing units -- such as size, insulation level, and geometry -- can be accounted for by easily calculated U-value-based correction factors. The survey procedure was developed with these two principles in mind.

Survey Preparation

Survey Training

A 2-day training session was held for the personnel involved in the surveys. During the training, teams were provided both an explanation of how and why survey items were required, and an overview of the BLAST input. Accuracy in the surveys was stressed. A military family housing unit was selected and each survey team had the opportunity to train on an actual house. Survey results of each team were discussed before the completion of the training.

Survey Procedure

The first step in the survey procedure was to appropriately group buildings to determine which units would require BLAST analysis. Three different groupings were used. Group 1 consisted of all family housing units in the metering demonstration program. After identification, the Group 1 buildings were divided into subgroups of thermodynamically identical buildings -- i.e., those designs built several times on one installation. More specifically, "thermodynamically identical" means that two buildings were alike with respect to their external structure (i.e., that portion of the building which is above ground level, including the roof) and that the cross section of the external structure was also identical (i.e., insulation levels and external wall construction). Two units were also considered identical if the only differences between them were:

1. Orientation of the buildings, or

2. Mirror imaging (i.e., right and left halves of otherwise identical duplex units), or

3. Arrangement of interior partitions.

Group 2, then, consisted of one building from each of the Group 1 subgroups of identical buildings.

Group 3 buildings were a representative sample of Group 2 buildings which typified the construction (frame, masonry, brick) and dwellings (single family, duplex, one- and two-story, townhouse) found on the installations. BLAST runs were made for the Group 3 buildings. The number of units selected for Group 3 was left to the judgment of the survey teams, with the requirement that if any of the units in Group 2 fell into the following categories, one representative sample from that category was to be included in Group 3.

1. One-story single family
2. Multistory single family
3. Duplex
4. Townhouse end unit
5. Townhouse center unit
6. Townhouse top floor
7. Townhouse lowest floor
8. Precast concrete construction
9. Frame construction
10. Brick/concrete block construction
11. Masonry/stone construction

Each dwelling type (1 through 7) did not have to be represented by each construction type (8 through 11).

The survey team was allowed to add units to Group 3 if it felt, after training in use of the survey form, that some feature of the building required that the building have a BLAST analysis. CERL determined, based on the survey sheets, how many of the Group 3 buildings actually required BLAST analysis.

Survey Form

The survey form shown in the appendix consists of pages for recording all basic information for the BLAST analysis, and supplemental sheets for floor, ceiling and roof, and exterior wall descriptions. For Group 3 buildings, the survey team completed the entire form (minus Question 18), and the required supplemental sheets.

For Group 2 buildings, Questions 1 through 18 of the basic form were completed. Since BLAST runs were not made on these buildings, the detailed building descriptions were not required. In place of the detailed building description was the simpler U-factor calculation of Question 18. From the results of this question, correction factors were developed from which the results of the BLAST analysis for the buildings could be extended to the Group 2 buildings.

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For Group 1 buildings, only questions 1 through 17 of the basic form were filled out. The answer to Question 18 was not required since it is the same as the Group 2 building identified on the cover sheet.

Determination of Norm Coefficients

Teams at each installation chose the representative Group 3 family housing units and, with the survey forms, performed a complete investigative survey of the units; these Group 3 survey packages were sent to CERL. CERL coded the buildings for input to the BLAST program, using the geometries and material description provided by the survey teams and the energy conservative specifications for thermostat settings and lighting/appliance use levels determined by DOD. With the BLAST program, each building was simulated in the orientation that would not penalize occupants for their energy use.

The Group 3 units at an installation were than analyzed by the BLAST program, using climatic data on a full year weather tape from a location most nearly matching the actual location of the housing units. The simulated energy consumption data by month from the BLAST program, and the corresponding data (heating degree days and the number of hours the ambient temperature exceeded $78^\circ F$ [$25.6^\circ C$]) from the weather tape, were extracted and tabulated. These data were then used in a nonlinear regression program to determine the coefficients used in the norm formula (Equations 8 and 10). The coefficients that provided the best curve fit to the simulated BLAST energy consumption were determined and provided to the Naval Facilities Engineering Command (NAVFAC) for input to the data base for the corresponding group of family housing units represented by that Group 3 unit. These regression coefficients were used in NAVFAC's billing program to determine the norm for each family housing unit in the test metering program demonstration.

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4 ANALYSIS OF DEMONSTRATION DATA

Data Availability

In the 1-year test metering demonstration, historical data tapes were produced by NAVFAC during each military family housing billing cycle. The data included the survey information for each family housing unit, the weather conditions, the actual consumption, and the calculated norm for each billing cycle. CERL recoded the NAVFAC data so it could be handled easily by the Statistical Package for the Social Sciences (SPSS), an integrated system of computer programs designed for analyzing scientific data. This program allows the user to select subgroups of data for extensive analyses, and then to compare these subgroups. The analyses were performed on groups of family housing units which were determined by survey to be thermodynamically equivalent. These groups were then subjected to mean, variance, and standard deviation computation to produce the curves and graphs in this chapter.

The data are based on a monthly proration of actual and norm consumption which NAVFAC used to produce monthly reports; these proration data were used in CERL's analysis. The proration of actual and norm consumption is not accurate enough for exact comparison with weather data; however, it provides a good basis for comparing actual consumption and norms over a continuous period of time, and will accurately show trends in the units' energy consumption.

Selection of Data

Data comparisons for actual and norm consumption of electricity and heating fuel were made for 15 types of units at Port Hueneme, CA; Cannon AFB, NM; Fort Gordon, GA; Quantico, VA; and Little Rock AFB, AK. These installations offered a variety of construction types and climates, and contained large groups of thermodynamically equivalent units -- so meaningful statistical samples could be obtained.

Electrical and Heating Analysis

Port Hueneme, CA

The first installation studied was Port Hueneme, which has 515 military family housing units. The housing units are provided with electricity and natural gas; the latter is used for domestic hot water heating, cooking, and space heating. The units are not air conditioned. The first units analyzed were single-story duplexes built in 1963 and containing 1262 sq ft (114.7 m^2). The three-bedroom unit is an uninsulated stucco building on a concrete slab, with a window area of 210 sq ft (19.1 m^2). The unit has a 72,000 Btu (7.6 x 10^7 J) per hour gas-fired furnace, a gas hot water heater, a gas range, and no cooling system. Figure 3 shows the mean electrical consumption, the mean norm, the maximum and minimum values of actual consumption in the sample, and the values associated with one standard deviation from the mean actual consumption. (The one standard deviation marks indicate that 68 percent of the actual data falls between these lines.) The low and high ranges indicate the minimum and maximum consumption in the sample. The data show that for this
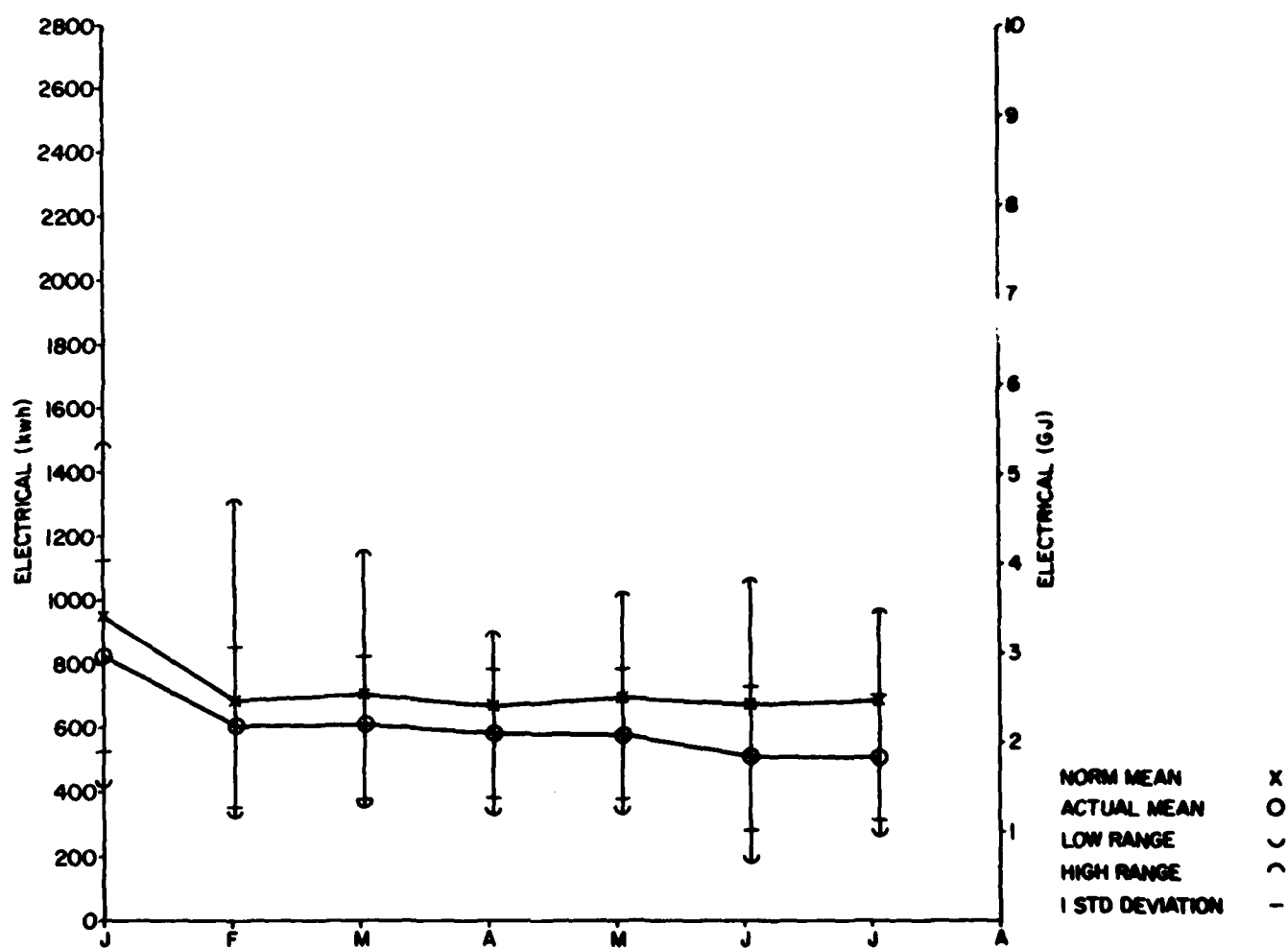
Figure 3. Electrical consumption and norm versus months (Port Hueneme).

three-bedroom unit, the actual consumption averages 15 percent below the norm. The actual mean and the norm for this unit tend to track (as one increases, the other increases) very well, which indicates that the monthly variation and electrical consumption provided by DOD for the norm prediction accurately reflect the diurnal electrical usage patterns. The actual and norm are closer during January through May than during June and July; this might be the result of the heating system's using less energy for fans during the summer months.

Figure 4 compares natural gas consumption with heating degree days for the same housing units. Again, the norm is higher than mean actual consumption. The norm baseline consumption for pilot lights and cooking is shown on this figure to indicate the contributors to the norm. The dashed line shows the calculated norm, including the heating norm as calculated by the heating algorithm. The norm is increased by an additional 4.7 CCF (hundred cubic feet) (133 m^3) per occupant for domestic hot water heating. The dotted line shows the norm consumption for four occupants in each building. It can be seen that the baseline norm (at 0 to 100 heating degree days) is about 1000 cu ft (28.3 m^3) higher than actual consumption, indicating that the baseline norms for pilots, cooking, and hot water heating are probably too high. The norm and the actual consumption track with each other quite well, as the heating degree days vary, indicating that the heating algorithm contains a suitable weather variable. Table 9 gives weather parameters for Port Hueneme.

The next building group studied was a 1415 sq ft (128.6 m^2) duplex unit built in 1963. The three-bedroom unit is an uninsulated stucco building on a concrete slab, with an attic and a window area of 231 sq ft (21 m^2). The building contains the same equipment as the one discussed above. Once again, as shown in Figure 5, the electric norm overpredicts by an average of 15 percent throughout the time of the study, indicating the norm for electrical consumption is set too high. The norm is closer to actual consumption during the early months of the year, and, as in the first building group, the variance tends to increase in the summer months -- suggesting the greater use of electricity in the winter for heating system fans.

Figure 6 shows gas consumption versus heating degree days for this group of buildings. These curves are very similar to those of the previous building, in that the norm is higher than the actual consumption -- except during the higher heating degree day months, when the norm mean and the actual mean are the same. Again, baseline norm is higher than actual usage. The excellent tracking of these two curves would also indicate that the norm is a better predictor during the higher heating-degree-day months than during the interim spring and fall seasons. Extremely wide fluctuations in actual consumption are evident in this sample of units, the minimum consumption and the maximum consumption are roughly 40 CCF (113 m^3) on both sides of the actual mean. This wide discrepancy could be caused by a number of factors, including variations in occupant lifestyle, indoor thermostat settings, and furnace efficiencies. Although the construction of these buildings is the same, some minor variations in orientation, window facing directions, and infiltration rates could also cause the units' minimum and maximum gas consumption to fluctuate.

A third building type studied at Port Hueneme was a 1426 sq ft (129.6 m^2) single-family, four-bedroom, one-story dwelling. The uninsulated stucco building has a 72,000 Btu (7.6 x 10^7 J) per hour gas furnace, a gas hot water
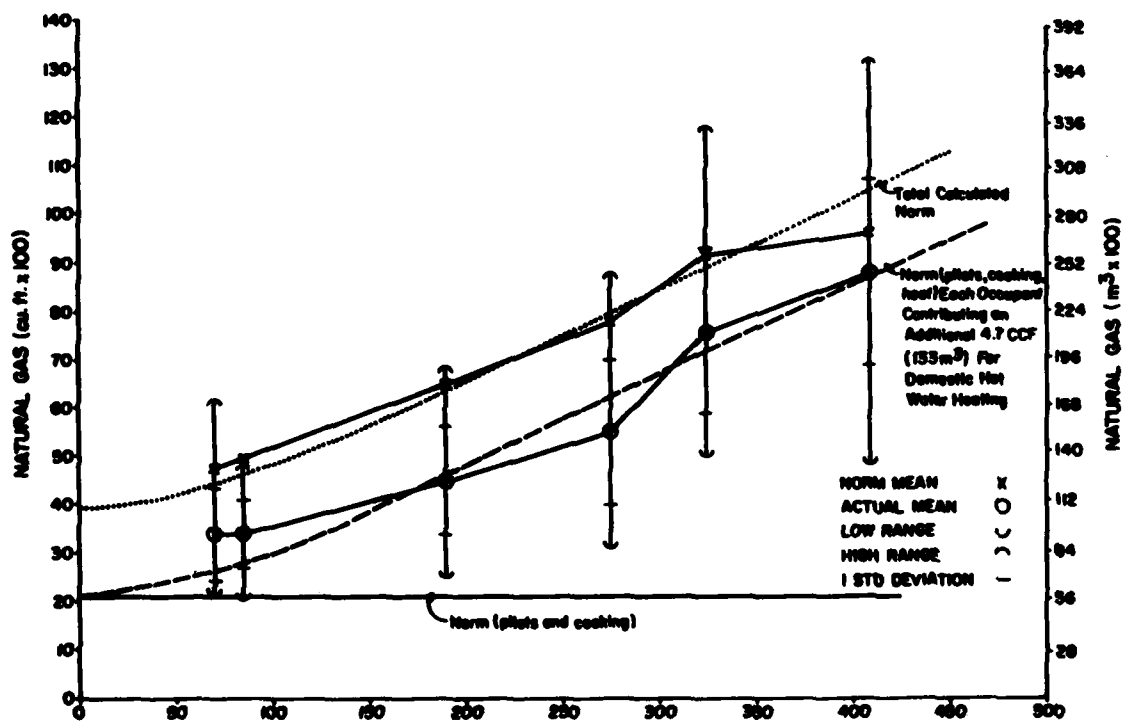
Figure 4. Gas consumption and norms versus heating degree days
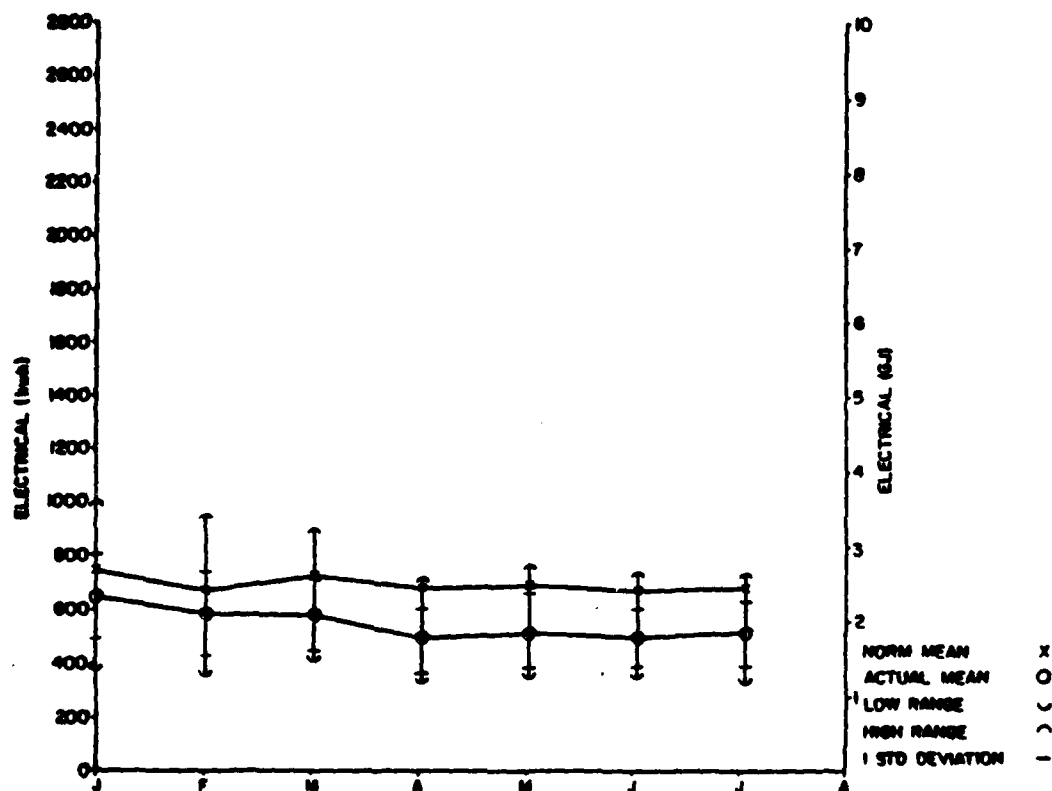(HDD) (Port Hueneme).

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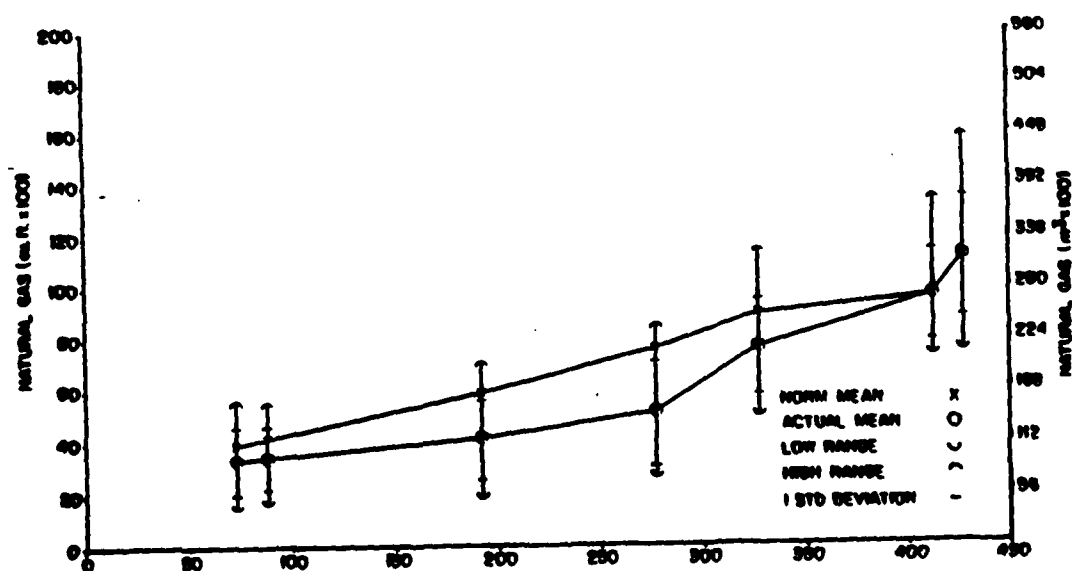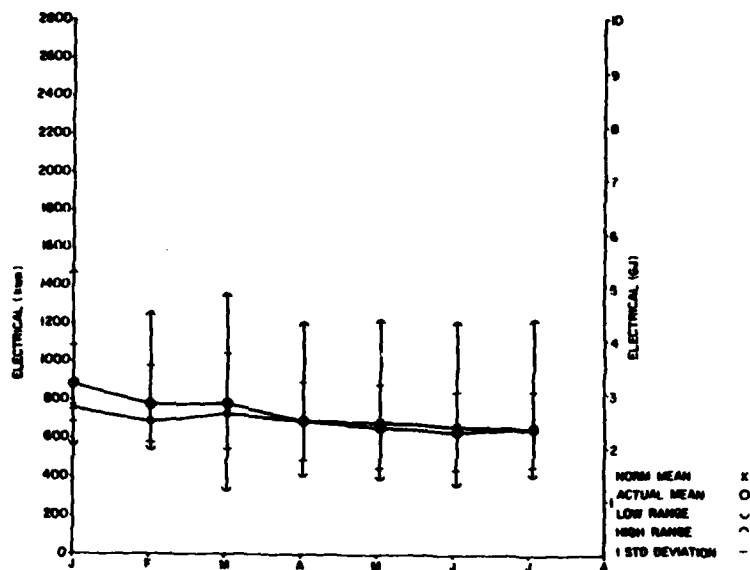Figure 5. Electrical consumption and norms versus months (Port Hueneme).

Figure 6. Gas consumption and norm versus HDD (Port Hueneme).

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Table 9

Weather Parameters: Port Hueneme

Month	Daily Heating Degree Days	Total Heating Degree Days	Hours Above 78°F (25.6°C)	Temperature of Water Supply, °F (°C)
Jan				
	58	328	7	65 (18.3)
Apr	9.20	276	--	65 (18.3)
May	6.12	190	11	65 (18.3)
Jun	2.76	83	25	65 (18.3)
Jul	2.32	72	--	25 (18.3)
Aug	--	--	--	65 (18.3)

heater, and a gas range. The building has a window area of 229 sq ft (20.8 m^2). Figure 7 shows the actual electrical consumption and norms for this building. In this building type, the actual mean consumption is higher than the norm for January through March, and nearly equal for the remaining months. As indicated by the previous electrical curves, the fan consumption factor for heating appears to be lower than it should be, based on actual consumption values obtained during the high-use months for heating systems. The variance between the low and high users is quite large -- about 800 kwh. The main difference between this building sample and those shown in Figures 3 and 5 is that it is a single-family, four-bedroom unit, instead of a three-bedroom, duplex unit. The average monthly consumption for the single-family, four-bedroom units is 100 kwh (3.6 x 10^8 J) per month higher than for the duplex three-bedroom units.

Figure 8 plots the natural gas consumption and norm against heating degree days. Trends for this building sample are the same as for the building samples illustrated in Figures 4 and 6. For this sample, the norm averages approximately 10 CCF (28 m^3) higher than the mean of the actual consumption. Again, although no single reason for this difference is evident, the nonheating baseline may have been set too high.

Cannon AFB

Cannon AFB has 1012 family housing accounts. The units are heated by natural gas, have gas hot water heaters and gas ranges, and are equipped with electric central air conditioners. The first building sample studied was a 993 sq ft (90.3 m^2), three-bedroom townhouse (center unit) with a window area

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Figure 7. Electrical consumption and norm versus months (Port Hueneme).
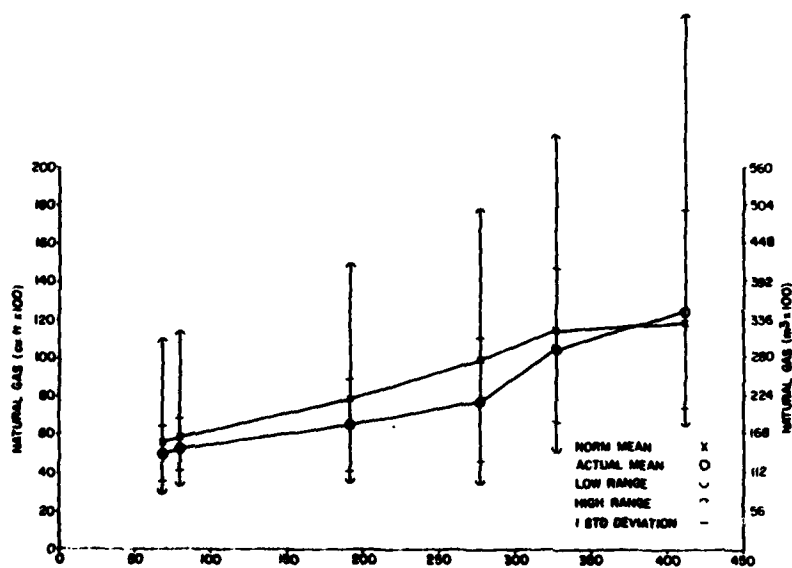
Figure 8. Natural gas consumption and norms versus HDD (Port Hueneme).

of 144 sq ft (13.1 m^2) and an infiltration/conduction factor of 10,521. The
units are brick and frame structures. Table 10 gives weather parameters for
Cannon AFB for the monitoring period. Figure 9, which illustrates the electr-
ical consumption and norms versus months for these units, shows that the norm
is consistently higher than the actual consumption; however, as the norm goes
up, actual consumption increases. Beginning in May, the increases resulting
from electric air conditioning are evident. The difference between the norm
and the actual consumption decreases during the summer months, indicating
either that the cooling algorithm underpredicts the actual cooling load, or
that the occupants are cooling their houses to less than 78°F (25.6°C). A
thermostat setting 2 degrees cooler can cause up to a 20 percent greater
electrical cooling requirement. Again, statistics indicate that the baseline
electrical norm tends to be high for this three-bedroom unit. The obvious
drop in electrical requirements during August results from the proration of
actual and mean data over a monthly period rather than over the actual billing
period, indicating that only a part of the August data was included. The
numbers in parentheses in Figure 9 show the number of hours that the outdoor
temperature exceeded 78°F (25.6°C). This weather parameter is used in the
norm algorithm to determine cooling load requirements.

Figure 10, which illustrates the gas consumption and norm versus heating
degree days, shows that for a very low number of heating degree days, the norm
is slightly lower (8000 cu ft or 226 m^3) than actual consumption; as the
number of heating degree days increases, actual consumption increases faster
than the predicted norm. The norm predominantly falls within the range of
actual consumption but does underpredict significantly. This could be due

Table 10

Weather Parameters: Cannon AFB

| Months	Daily Heating Degree Days	Total Heating Degree Days	Hours Above 78°F (25.6°C)	Temperature of Water Supply, °F (°C)
January	34.96	1084	0	68 (20)
February	24.32	681	3	68 (20)
March	17.38	539	2	68 (20)
April	8.80	264	28	68 (20)
May	3.54	110	87	68 (20)
June	1.13	34	191	68 (20)
July	—	—	318	68 (20)
August	—	—	242	68 (20)
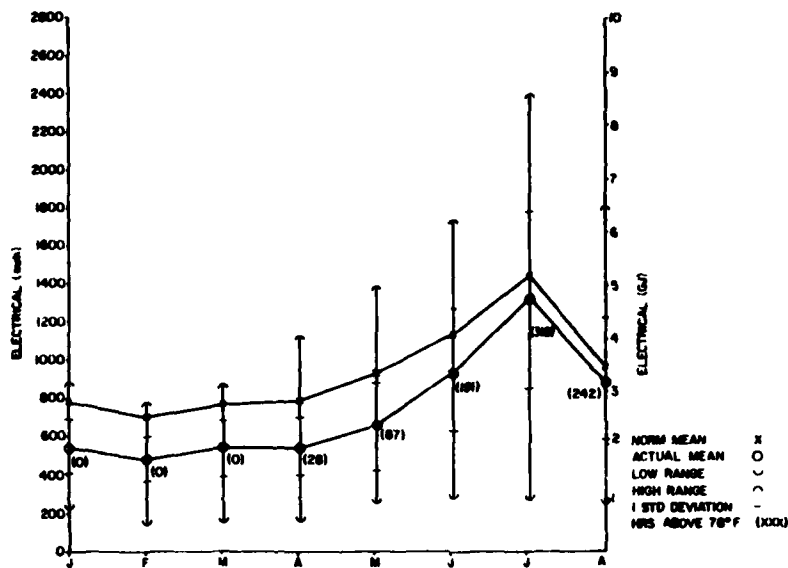
Figure 9. Electrical consumption and norms versus months (Cannon AFB).
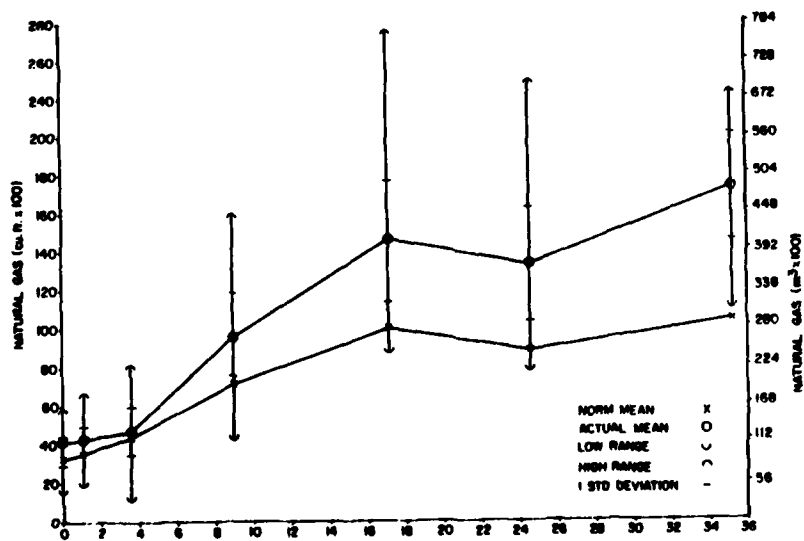
Figure 10. Gas consumption and norm versus daily HDD (Cannon AFB).

either to higher actual thermostat setting in the units, or to a higher-than-actual furnace efficiency selected for the building. The fact that the norm mean and the actual mean track accurately indicates that the norm heating algorithm accurately predicts trends in gas consumption.

Figure 11, which shows a frequency distribution of gas use for this unit during January, indicates the extreme variances between minimum and maximum use. This sample includes 46 thermodynamically equivalent family housing units. Figures 12 and 13 show the frequency distribution of gas use for February and March, respectively. Again, the large variance between the low and high users is evident. The larger group of cases within the midportion of the figures and the general "bell" shape of the plotted data indicate that these data are valid as a statistical sample.

The next building studied was identical to the previous unit, except that it was the end unit on the townhouse. This unit had a slightly higher infiltration/conduction factor of 10,989. Figure 14 compares the electrical consumption for this type of unit with the norms. The norm is higher than the mean of the actual consumption throughout the winter months, but the variance decreases during the summer months, supporting the theory that either the units are being cooled to temperatures below 78°F (25.6°C), or that the cooling algorithm underpredicts the building's cooling requirements. The trends indicated in Figure 14 support the DOD diurnal variation in electrical consumption, since the norm and actual curves track well until cooling energy becomes a significant portion of the total.

Figure 15, which shows the gas consumption and norms versus heating degree days, is very similar to Figure 10; however, a comparison shows that the end unit uses approximately 30 CCF (85 m^3) more energy per month during the heating season than the center units. Such higher consumption would be expected since the end unit has a greater amount of wall area exposed to the exterior environment. The factors influencing the variance between norm and actual consumption are the same as for the center unit.

Figure 16 shows actual and norm electricity consumption data from a sample of 140 single-story duplexes having an area of 1560 sq ft (141.8 m^2). The buildings in this sample were built in 1974 and have a window area of 193 sq ft (17.5 m^2); as shown in the Port Hueneme data, this four-bedroom unit uses roughly 100 kwh (3.6 x 10^8 J) more per month than the smaller three-bedroom units. The trends of the actual and the norm track well. It is evident from this curve, as was also shown in Figures 12 and 14 that either the cooling algorithm tends to underpredict the building's cooling requirements or the occupants are cooling their facilities to temperatures below 78°F (25.6°C), thus increasing energy consumption. The norm always falls within one standard deviation from the actual consumption, showing that even though the norm is low, it is a reasonable numerical value since many of the units actually use less energy than the norm allows.

Figure 17 shows the gas consumption and norms versus daily heating days for this unit; the norm is consistently lower than the actual mean data. This unit, which has an infiltration/conduction factor of 15,621 (compared with 10,984 for the unit in Figure 15), uses 50 percent more heating energy than the townhouses plotted in Figure 15. This shows that the infiltration/conduction factor is a valid method of describing and adjusting a
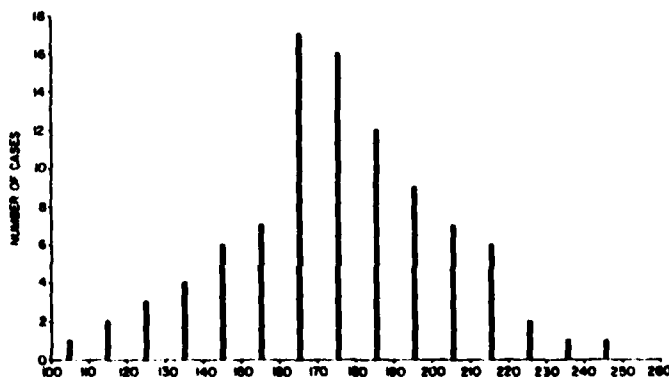
Figure 11. Frequency distribution of gas usage -- January.
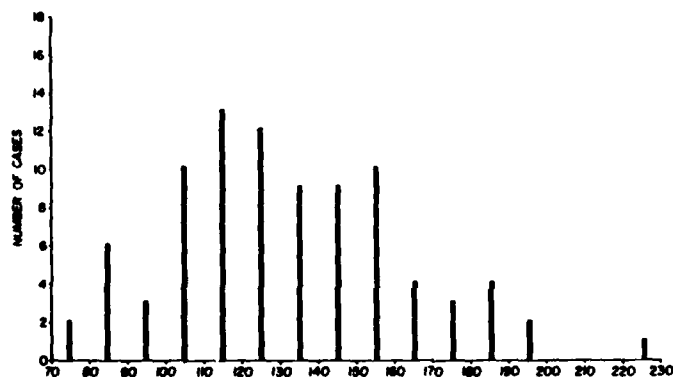
Figure 12. Frequency distribution of gas usage -- February.
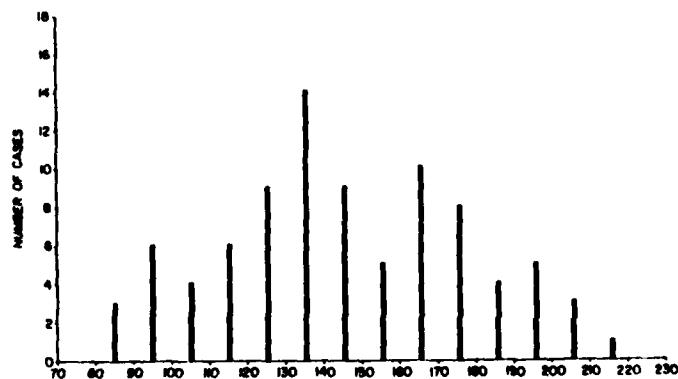
Figure 13. Frequency distribution of gas usage -- March.

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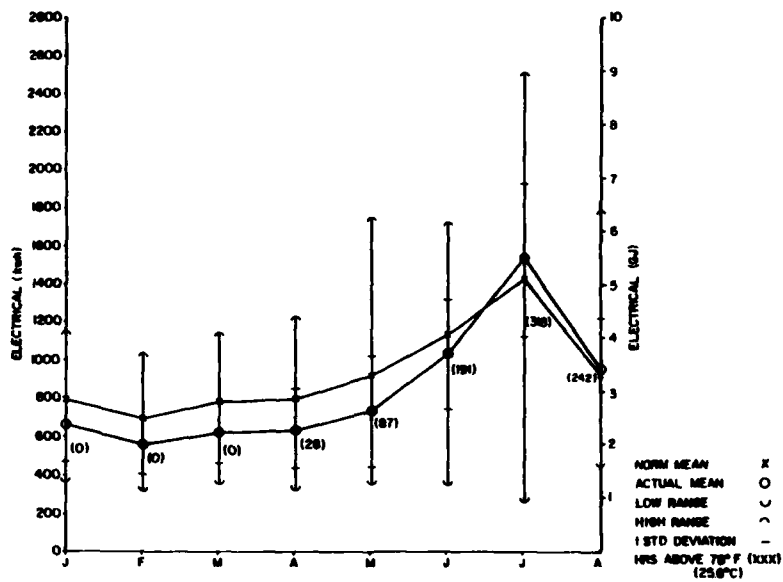
Figure 14. Electrical consumption norms versus months (Cannon AFB).
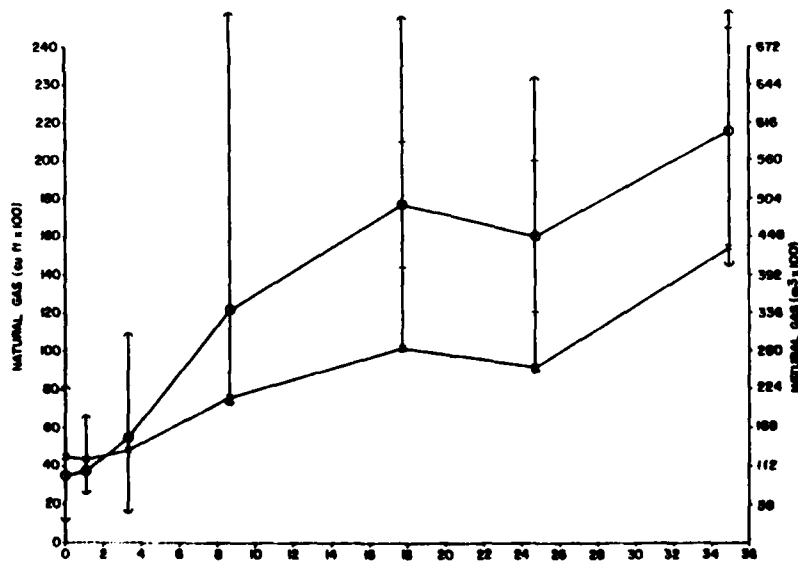
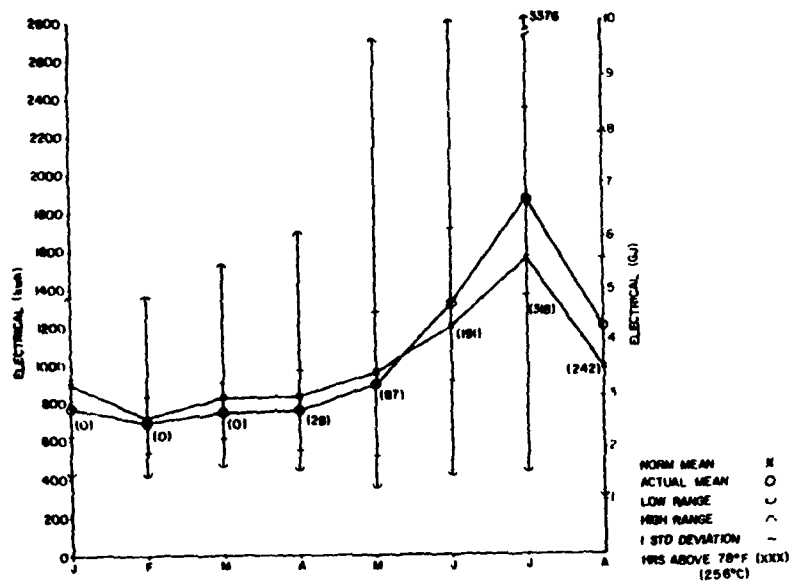Figure 15. Gas consumption and norms versus daily HDD (Cannon AFB).

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Figure 16. Electrical consumption and norms versus months (Cannon AFB).
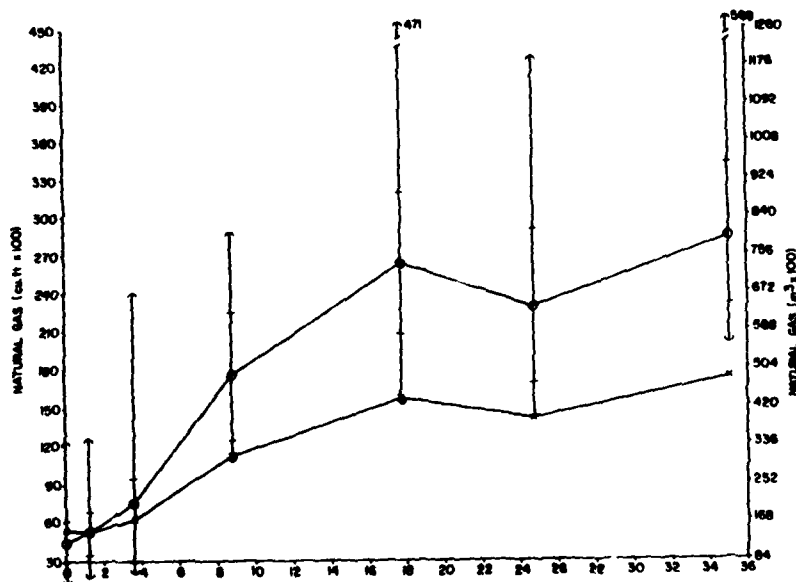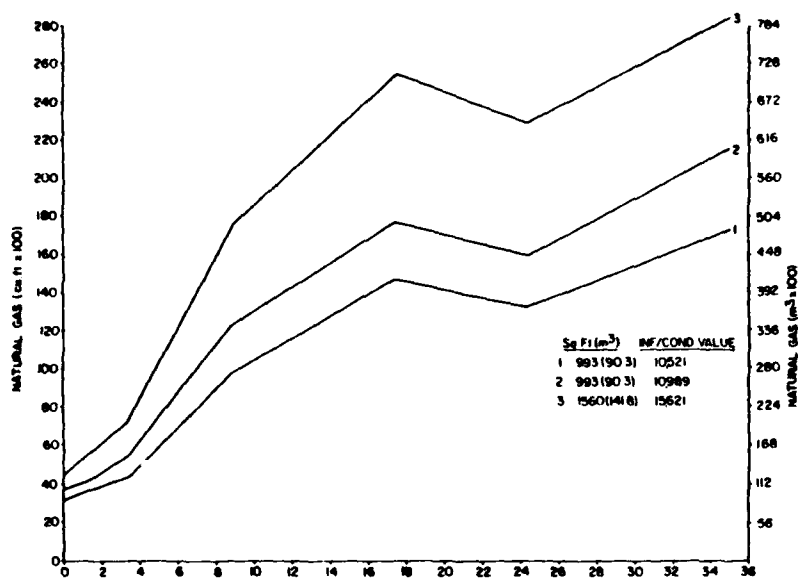

Figure 17. Gas consumption and norms versus daily HDD (Cannon AFB).

housing unit's thermodynamic operation. The tracking of the norm and actual consumption illustrates the algorithm's ability to predict heating requirements based on heating degree days. However, the difference between the norm and the actual is fairly large (30 percent), indicating that there may have been some major problem with the survey definition of this building type or excessive indoor temperatures are being maintained in the actual units.

Figure 18 provides the gas consumption and norms versus daily heating degree days for the three units studied. The heating consumption curves have the same general shape, indicating that the heating degree day method for predicting heating consumption is theoretically sound.

Quantico, VA

Table 11 shows weather parameters for Quantico, which has 1110 family housing units. Heating is primarily by natural gas, but propane is used in some units. The first building studied was a two-bedroom family housing unit built in 1952, having an area of 808 sq ft (73.5 m^2). The unit is a center townhouse, two-story unit which uses natural gas for heating, cooking, and domestic hot water. The building has an infiltration/conduction factor of 11,729. Figure 19, which illustrates the electrical consumption and norms versus months for this unit, shows that the mean actual consumption is higher than the norm. The shapes of the two curves are very similar; however, as cooling energy is required, the cooling norm is lower than actual consumption, as was also indicated by the Cannon AFB data.

Table 11

Weather Parameters: Quantico

Month	Daily Heating Degree Days	Total Heating Degree Days	Hours Above 78°F (25.6°C)	Temperature of Water Supply, °F (°C)
January	25.35	786	--	50 (10)
February	31.03	869	--	43 (6.1)
March	12.96	402	4	49 (9.4)
April	8.46	254	--	57 (13.9)
May	1 22	38	43	63 (17.2)
June	0.40	12	92	76 (24.4)
July	--	--	180	84 (28.9)
August	--	--	152	83 (28.3)

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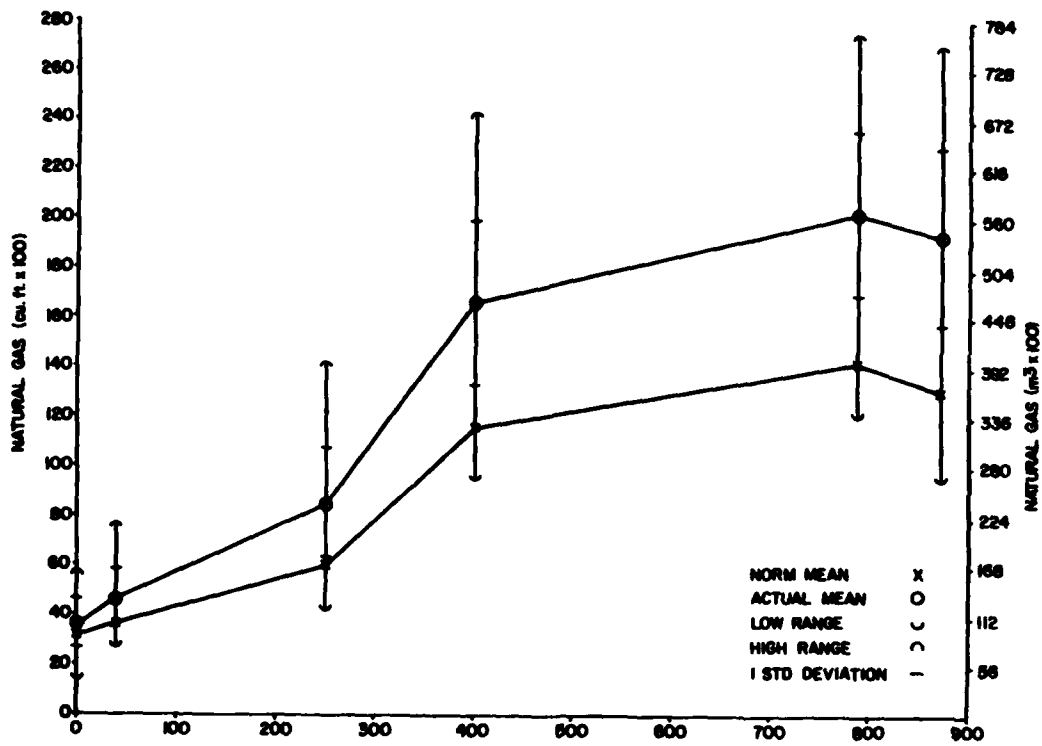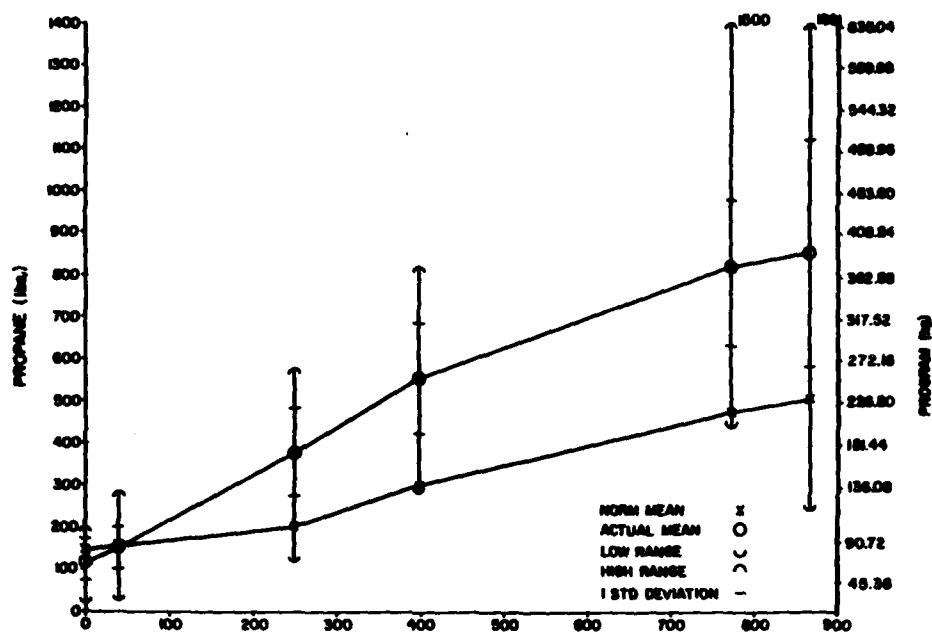Figure 18. Gas consumption and norms versus daily HDD (Cannon AFB).
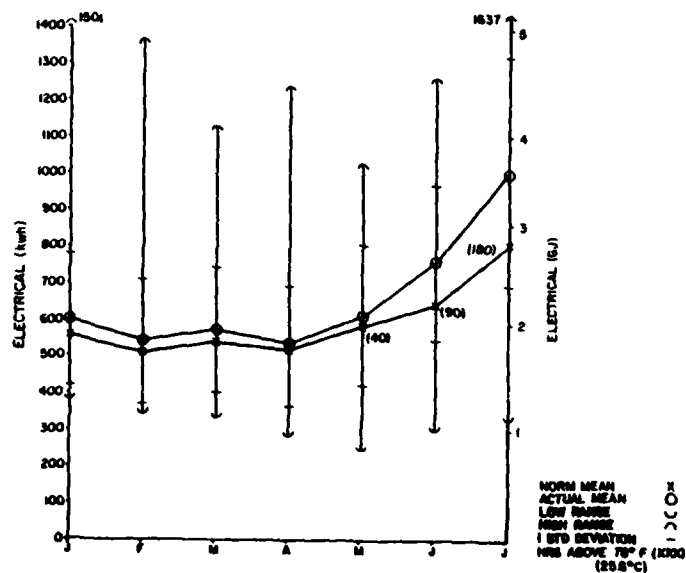
Figure 19. Electric consumption and norms versus months (Quantico).

Figure 20 shows the gas consumption and norms versus heating degree days for this unit. For each month, the actual consumption is higher than the norm — which does, however, fall within the range of actual consumption. Again, a very wide fluctuation in actual energy requirements is evident among thermodynamically equivalent family housing units. An example shown at the 400 heating degree days mark indicates a minimum consumption of 9400 cu ft (266 m^3) and a maximum consumption of 24,200 cu ft (685 m^3) for separate but thermodynamically equivalent units. The norm tracks well with actual consumption for these units.

The next building group studied was a 693 sq ft (63 m^2) two-bedroom unit, with 81 sq ft (7.4 m^2) of window area. This building is a frame duplex built in 1942, uses propane for heating, cooking, and domestic hot water heating, and has an infiltration/conduction factor of 11,937. Figure 21 shows the electrical consumption for this unit. The actual electrical consumption is less than one half of the norm, but does track well with the norm consumption. Initial analyses of these data indicate that either the actual consumption meters or the meter conversion factor may be in error, since actual consumption is very low for this type of unit. This was the widest variation found between actual and norm electrical data in the family housing units. As with the electrical consumption and norm statistics given for other activities analyzed, the differences during the summer months when cooling is required are less than in the winter months, which indicates greater consumption by the cooling system than was predicted by the cooling algorithm.

Figure 22 shows the propane consumption and norms versus heating degree days for this unit. While the norm and the actual are very close during the low heating degree day months, a larger difference is noted during the heating season. Although the two curves track well, and the norm falls within the range of actual consumption, the wide variation cannot be explained without an on-site evaluation.

A third building type studied at Quantico was a 1277 sq ft (116.1 m^2), three-bedroom unit containing 297 sq ft (27 m^2) of window area. The single-family, one-story, frame structure was built in 1962 and has an infiltration/conduction factor of 19,365. Figure 23 shows the electrical consumption for the group of buildings. Although the norm is higher than average actual consumption, the variance falls within the range of actual, and the one standard deviation marks on the curve indicate a reasonable and equitable norm for this building type.

Figure 24 shows the gas consumption and norms versus heating degree days for this unit. Although the norm is slightly less than actual consumption for most of the period, it generally tracks well with actual consumption, and during the higher heating degree months, actual and norm consumption agree to within 2 to 3 percent and always fall within one standard deviation.

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Figure 20. Gas consumption and norms versus HDD (Quantico).
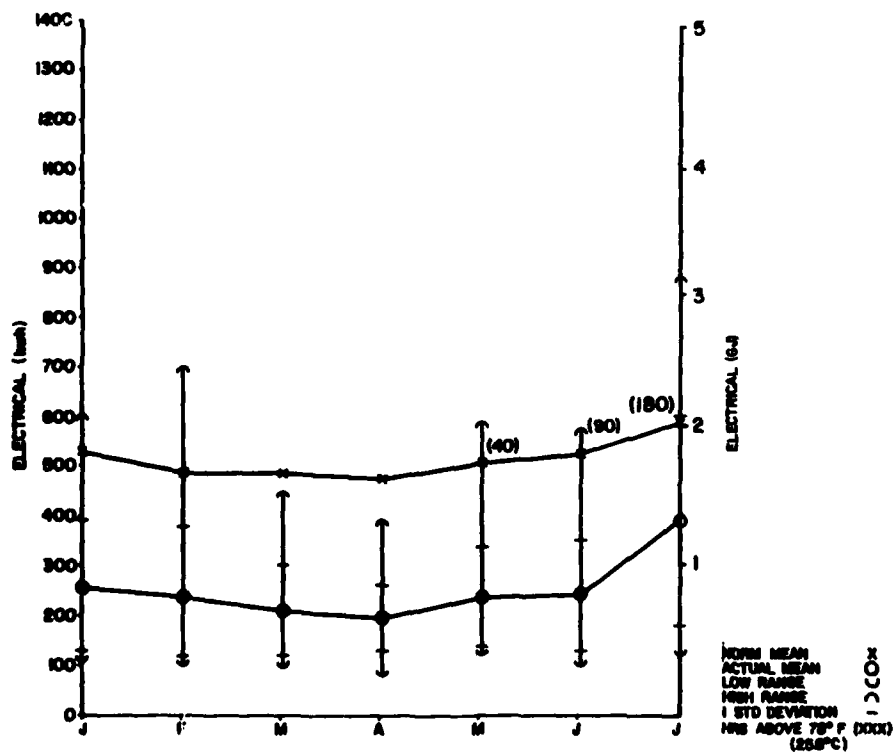
Figure 21. Electric consumption and norms versus months (Quantico).

Figure 22. Gas consumption and norms versus HDD (Quantico).
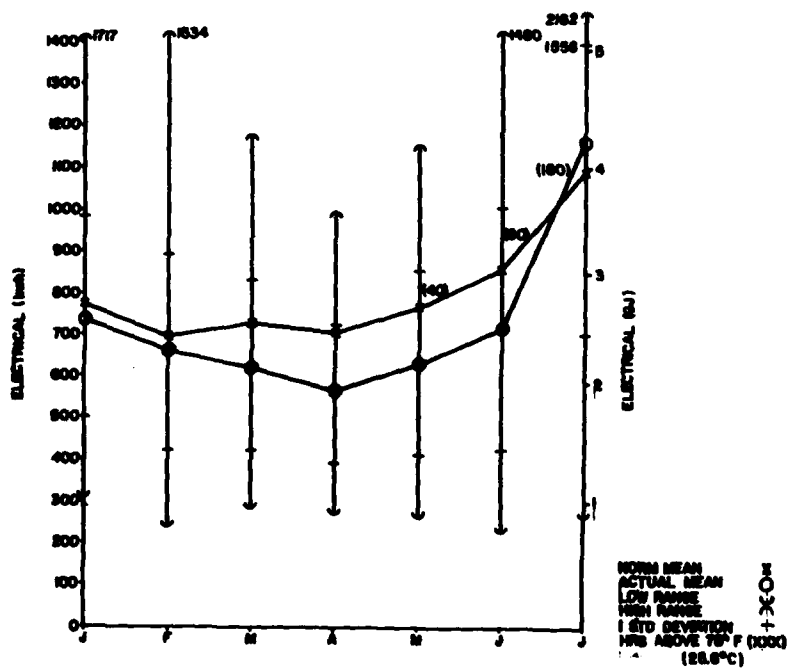
Figure 23. Electric consumption and norms versus months (Quantico).
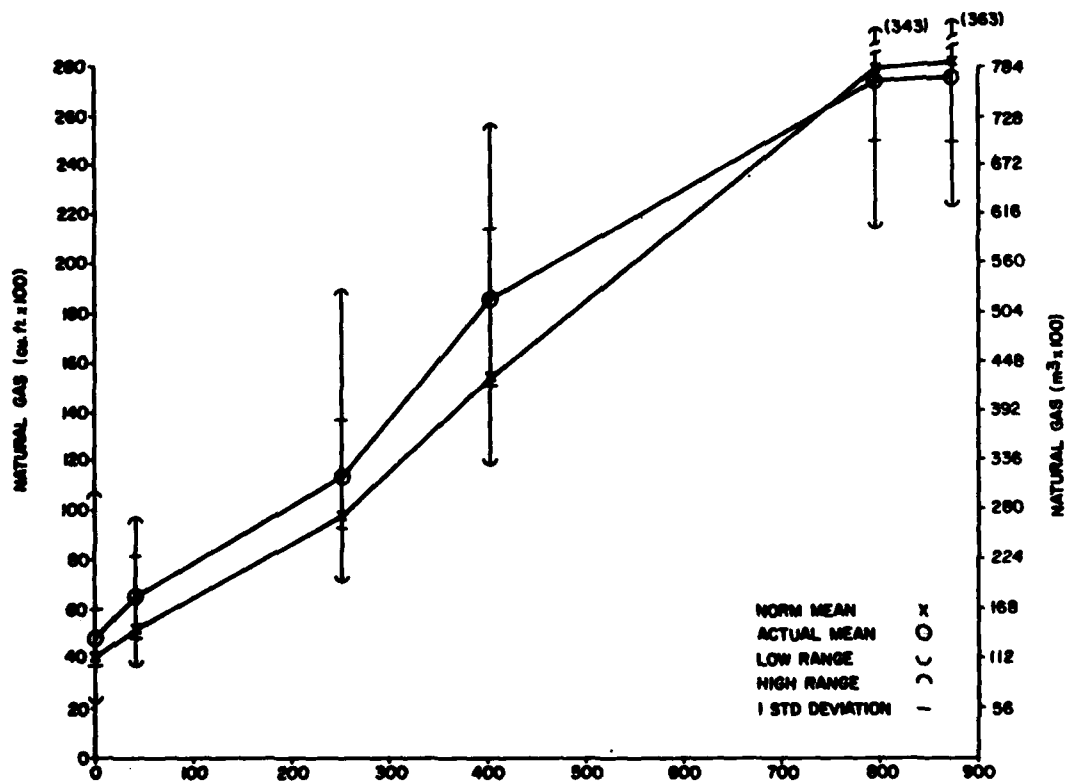
Figure 24.   Gas consumption and norms versus HDD (Quantico).

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Fort Gordon, GA

Table 12 gives weather parameters for the monitoring period for Fort Gordon, GA, which has 593 family housing accounts. The family housing units use natural gas for heating, cooking, and hot water, and have central electrical air-conditioning units serving each unit. The first building type studied was a 1378 sq ft (125.3 m²) frame townhouse center unit. The two-story, three-bedroom unit was built in 1967, has a window area of 174 sq ft (15.8 m²) and an infiltration/conduction factor of 12,291. Figure 25 shows the electrical consumption for this sample of 86 thermodynamically equivalent units versus the months of data collection. The numbers in parentheses indicate the hours that the outdoor temperature exceeded 78°F (25.6°C). The norm is approximately 100 kwh (3.6×10^8 J) higher than the actual consumption mean. Figure 25 shows that cooling was apparently not used until May; however, the cooling algorithm calculates a cooling consumption whenever outdoor air temperature exceeds 78°F (25.6°C), as in March when 53 cooling hours were recorded. This increase in the norm when the occupants do not use cooling causes a difference between the norm and actual consumption during the months of May and April; however, after air conditioning was turned on in the facilities, the norm and the actual track very well for the remainder of the cooling season.

Figure 26 shows the natural gas consumption and norms versus the heating degree days at Fort Gordon. The norm is slightly lower than, but very close to, actual consumption during the very low (less than 100) heating degree days, but the variance increases to approximately 2000 cu ft (56.6 m³) for the remainder of the heating season. This could be the result of factors such as

Table 12

Weather Parameters: Fort Gordon

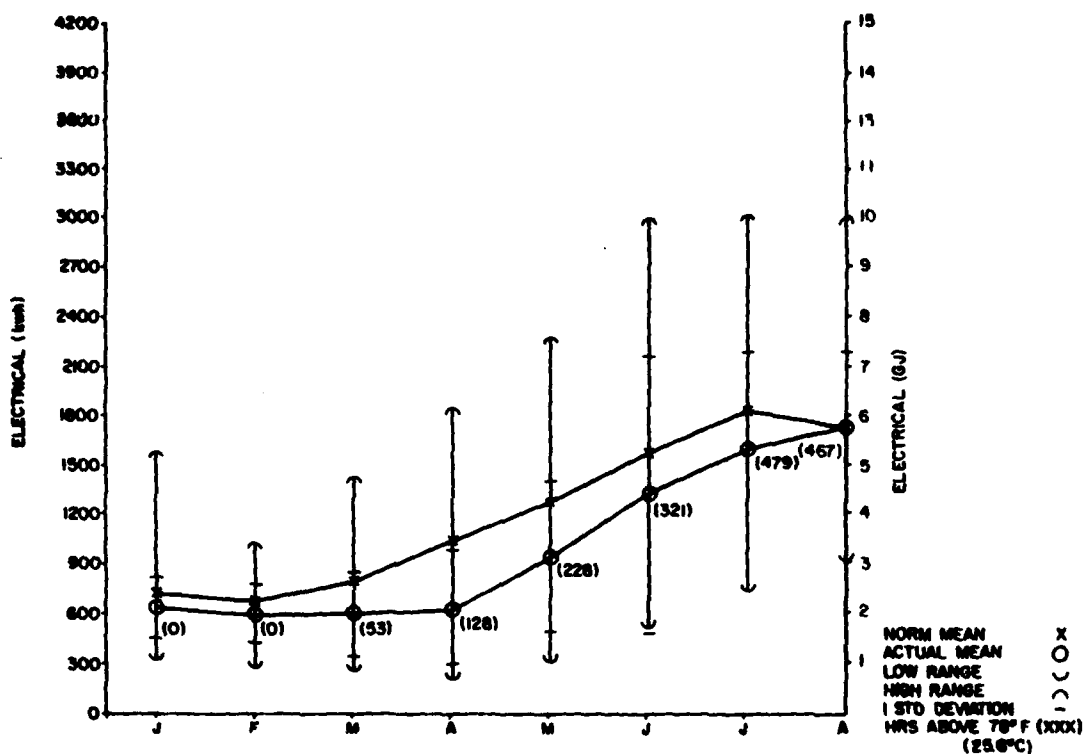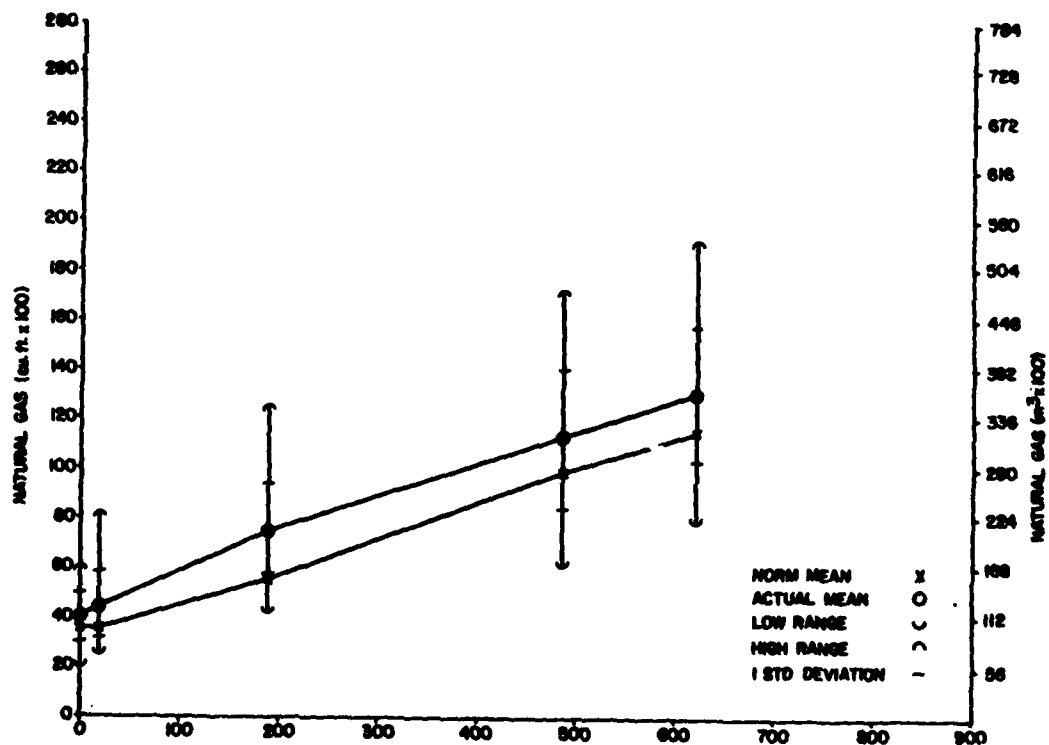| Month	Daily Heating Degree Days	Total Heating Degree Days	Hours Above 78°F (25.6°C)	Temperature of Water Supply, °F (°C)
January	19.83	615	--	49 (9.4)
February	17.28	484	--	49 (9.4)
March	6.19	192	53	58 (14.4)
April	.40	12	128	66 (18.9)
May	.29	9	228	72 (22.2)
June	--	--	331	78 (25.6)
July	--	--	479	80 (26.7)
August	--	--	467	81 (27.2)
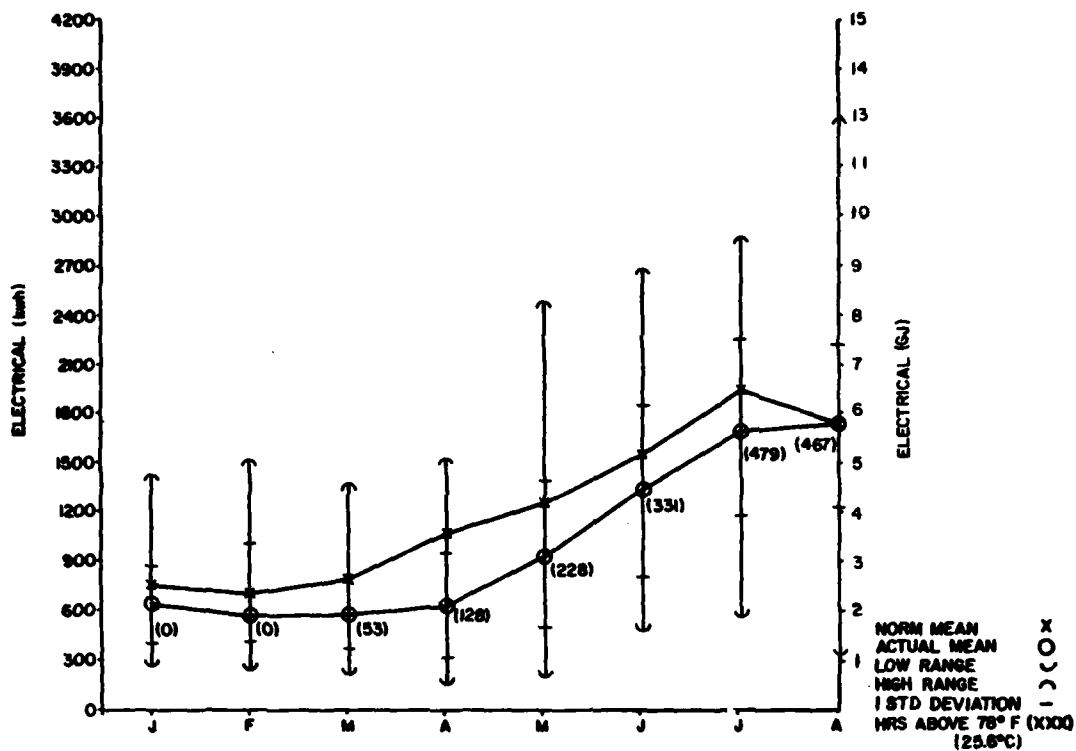
Figure 25.   Electrical consumption and norms versus months (Fort Gordon).
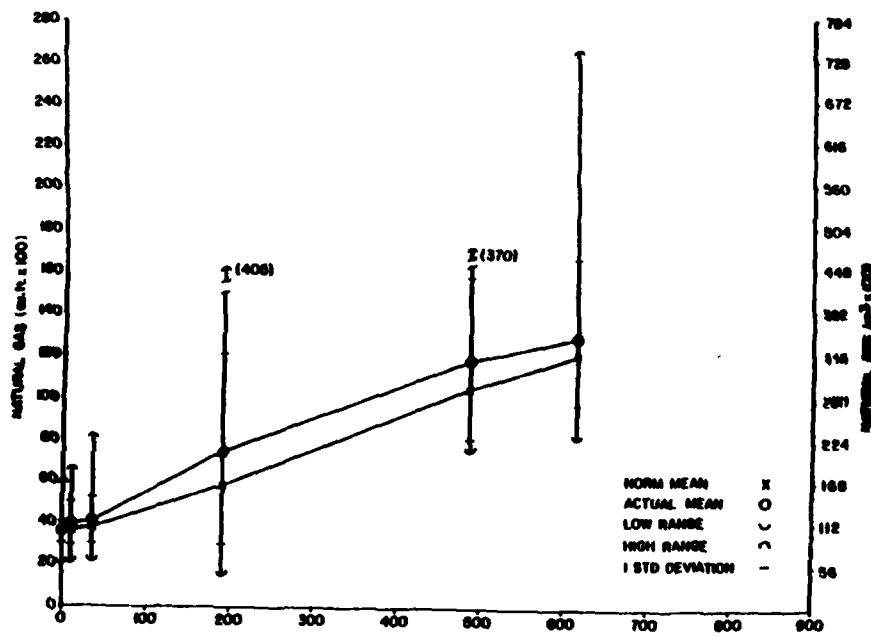
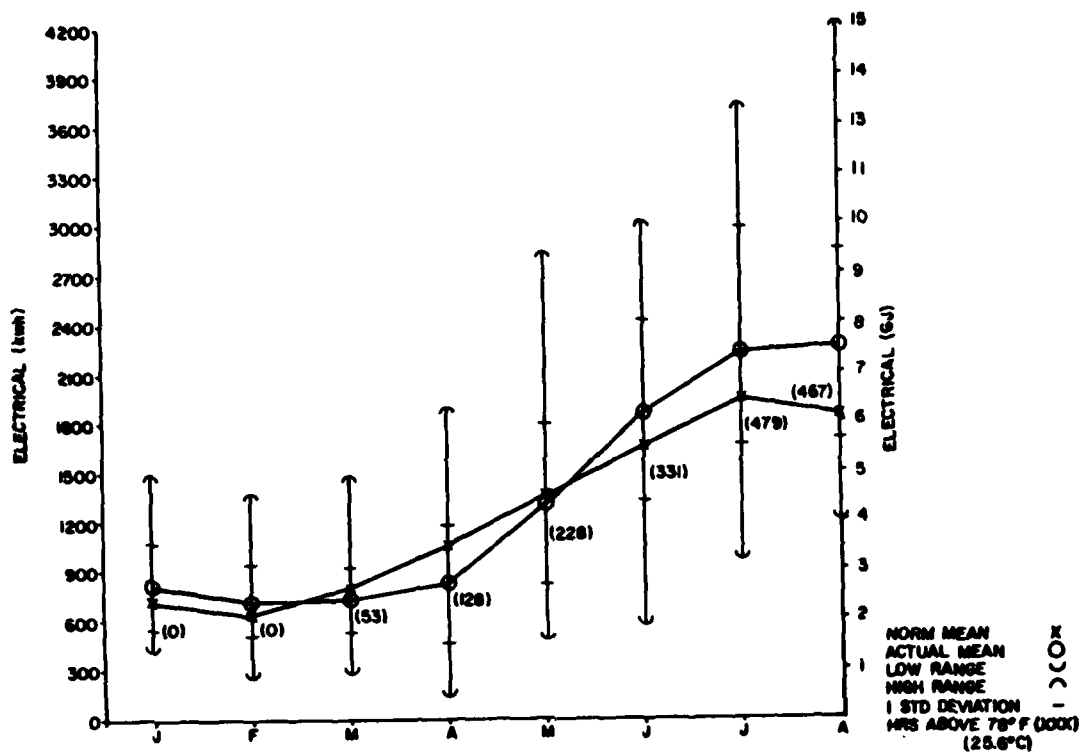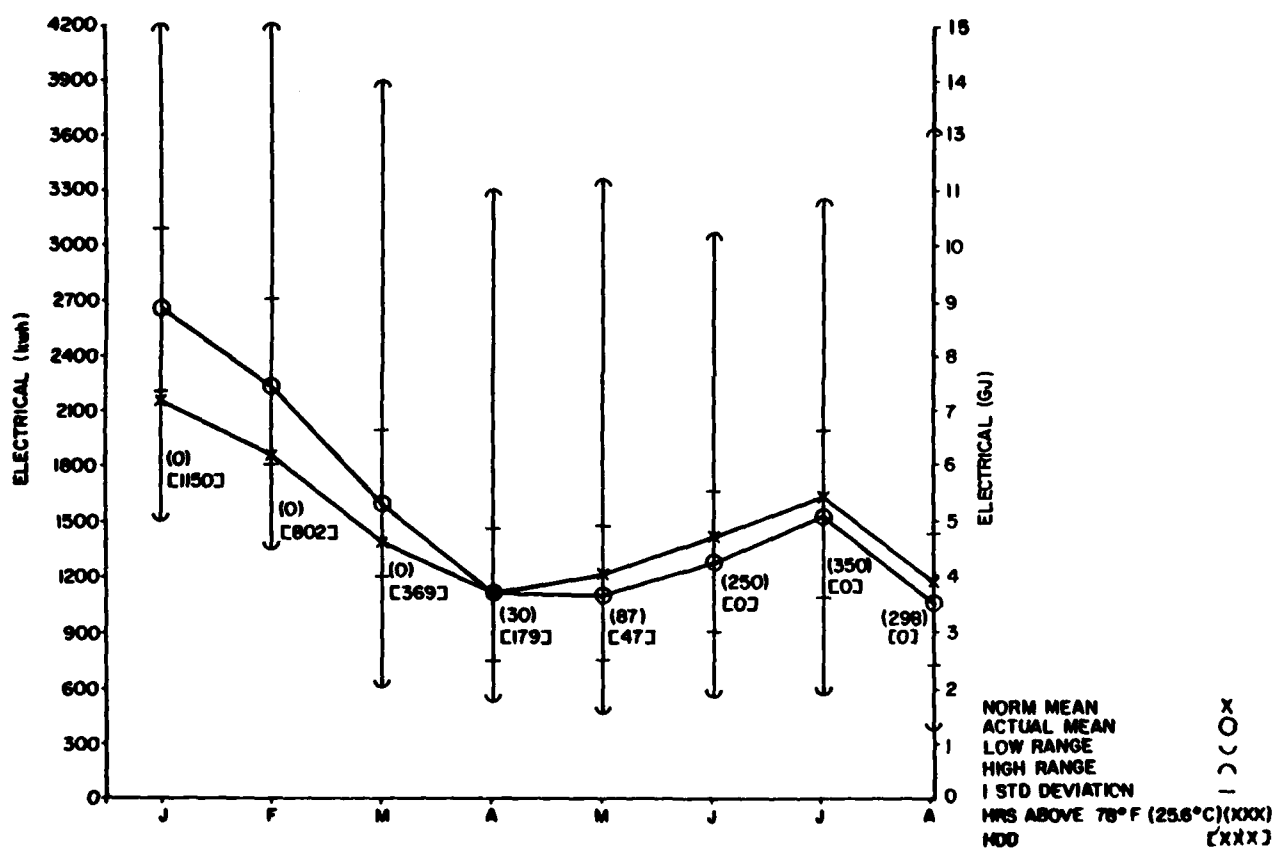Figure 26.   Gas consumption and norms versus HDD (Fort Gordon).

improper infiltration/conduction factors, higher-than-actual furnace efficiencies, or indoor thermostat settings exceeding 68°F (20°C) in the actual sample units. Simple adjustments to these factors in the norm formula could bring these curves together exactly.

The second building studied at Fort Gordon was identical to the first, but was the end unit of a townhouse. This frame structure has three bedrooms, and its conduction/infiltration factor is 11,927. Figure 27 shows an electrical consumption and norms versus months for this sample of 85 thermodynamically equivalent buildings. The trend is the same as that shown in Figure 25, where the norm mean increases as the hours the temperature exceeds 78°F (25.6°C) increase, but the actual consumption does not begin increasing until May, when air conditioners are used. The same 100 kwh (3.6 x 10^8J) difference during the noncooling hours is also evident for this building type, indicating that the basic electrical norm is high for two- and three-bedroom buildings.

Figure 28 shows the gas consumption and norms for this sample of thermodynamically equivalent buildings. This curve is similar to Figure 26, where the norm is lower than actual consumption, but tracks very well throughout the increase in heating degree days.

The last building studied for Fort Gordon was a 1556 sq ft (141.4 m^2) townhouse end unit. This two-story frame structure, built in 1967, is a four-bedroom unit with 217 sq ft (19.7 m^2) of window area and an infiltration/conduction factor of 14,726. Figure 29 shows the electrical consumption versus months and hours above 78°F (25.6°C) for this facility. The actual mean consumption during noncooling months is approximately 100 kwh (3.6 x 10^8J) higher than the norm calculated value until cooling hours begin to increase the norm. Air conditioning is not used much until May; at this time, actual consumption increases faster than predicted by the norm cooling algorithm, suggesting that indoor thermostat settings are lower than 78°F (25.6°C).

Figure 30 shows the gas consumption and norm versus heating degree days for this sample of 68 thermodynamically equivalent buildings. This curve is similar to those in Figures 26 and 28; i.e., gas consumption in the very low heating degree day months is very close to the norm, but the variance becomes greater than actual consumption for the remaining period of higher heating degree days.

Little Rock AFB, AR

Table 13 gives weather parameters for Little Rock AFB, AR, which has 1538 family housing units. All family housing units use only electricity for heating, cooking, cooling, and domestic hot water heating.

The first building studied was a 940 sq ft (85.4 m^2) frame duplex built in 1958. The two bedroom, one-story structure contains 115 sq ft (10.4 m^2) of window area and has an infiltration/conduction factor of 6504. Figure 31 shows the electrical consumption and norms by month for this sample of 323 thermodynamically equivalent buildings. The bracketed numbers indicate the number of heating degree days during a particular month. Analysis of the curves in Figure 31 is slightly more complex than for others shown previously.

Figure 27.   Electrical consumption and norms versus months (Fort Gordon).

Figure 28.   Gas consumption and norms versus HDD (Fort Gordon).

Figure 29. Electrical consumption and norms versus months (Fort Gordon).
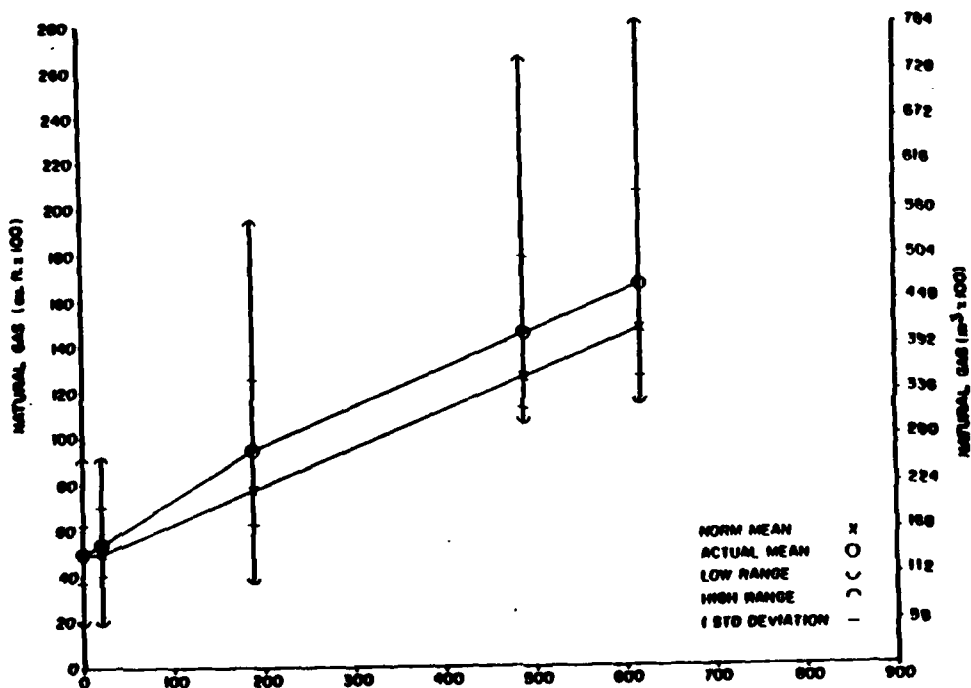
Figure 30. Gas consumption and norm versus HDD (Fort Gordon).

4200

3900

3600

3300

3000

2700

2400

ELECTRICAL (kwh)

2100

1800

1500

1200

900

600

300

0

J F M A M J J A

(0)
[1150]

(0)
[802]

(0)
[369]

(30)
[179]

(87)
[47]

(250)
[0]

(350)
[0]

(298)
[0]

18

14

13

11

10

9

8

7

6

5

4

3

2

1

0

ELECTRICAL (GJ)

NORM MEAN   X
ACTUAL MEAN   O
LOW RANGE   ∪
HIGH RANGE   ∩
I STD DEVIATION   I
HRS ABOVE 78°F (25.6°C)(XXX)
HDD   [XXX]

Figure 31. Electrical consumption and norms versus months (Little Rock AFB).

Table 13

Weather Parameters: Little Rock AFB

Month	Daily Heating Degree Days	Total Heating Degree Days	Hours Above 78°F (25.6°C)	Temperature of Water Supply, °F (°C)
January	37.09	1150	--	44 (6.7)
February	28.64	802	--	44 (6.7)
March	11.90	369	--	53 (11.7)
April	5.96	179	30	61 (16.1)
May	1.51	47	87	65 (18.3)
June	--	--	250	72 (22.2)
July	--	--	354	76 (24.4)
August	--	--	298	77 (25.0)

During the heating months, actual consumption is higher than norm consumption, but tends to merge and then become lower than the norm when heating is no longer required and cooling becomes a significant portion of the electrical load. During the cooling months, norm consumption is about 10 percent higher than actual mean consumption. The two curves track very well for the heating periods and cooling periods, individually. The norm and actual vary more widely for January than for March and April because of the heating system coefficient of performance (reciprocal of efficiency) for the heat pumps. A constant heat pump coefficient of performance was used to calculate the norm. Since heat pumps (in the heating mode) are more efficient in warmer months, a variable coefficient of performance based on the number of heating degree days should be developed and added to the norm calculations procedure in order to determine the building's consumption more accurately.

The second building studied at Little Rock AFB was a 1052 sq ft (95.6 m^2) single-story duplex. This three-bedroom frame has 142 sq ft (12.9 m^2) of window area and an infiltration/conduction factor of 7651. Figure 32 shows the total electrical energy consumption and norms versus heating degree days and hours above 78°F (25.6°C). This curve is very similar to that shown in Figure 31, where the actual consumption is higher than the norm consumption during the heating months and lower during the cooling months. Thus, for this installation, the total norm algorithm prediction is too high for heating and too low for cooling. The fact that the two curves track well indicates that minor adjustments to the norm algorithm will decrease the variance between norm and actual.

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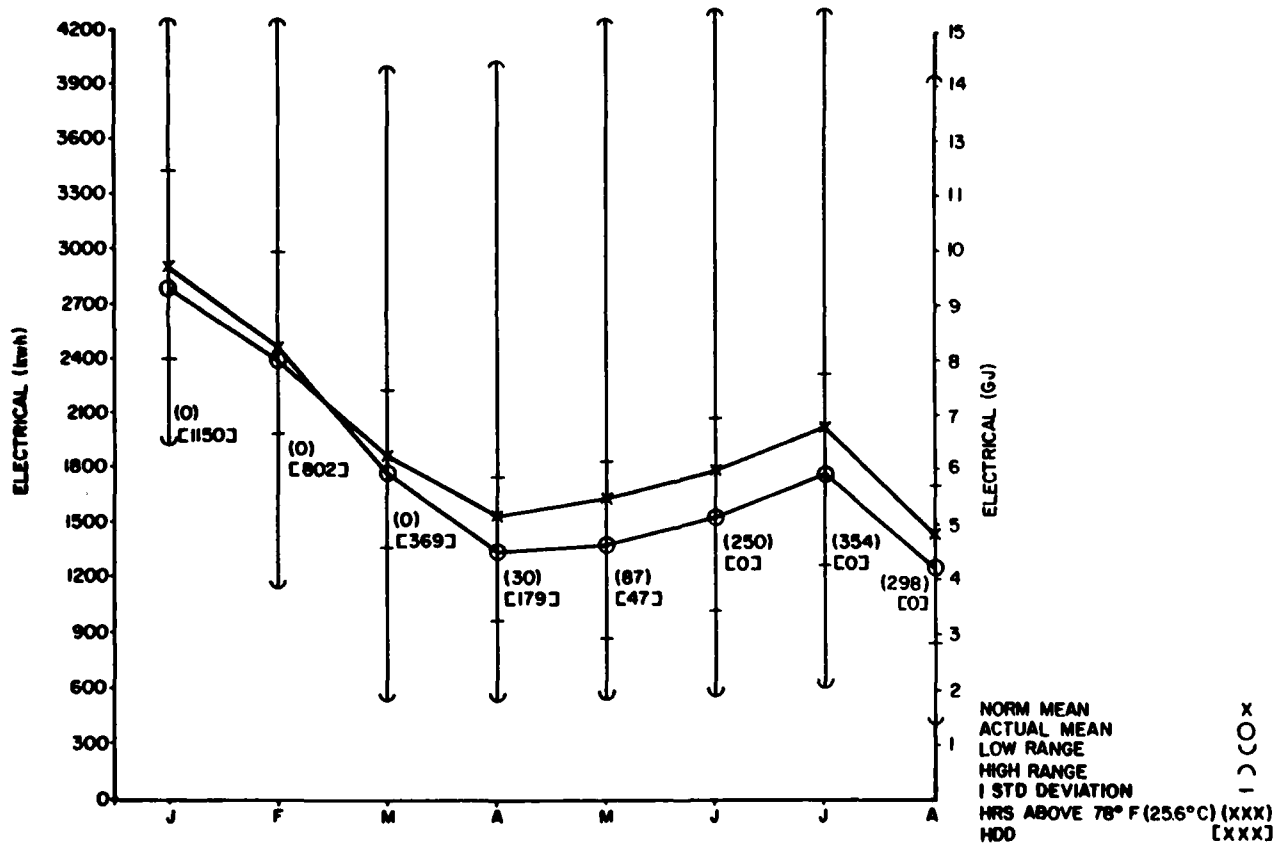
Figure 32. Electrical consumption and norms versus months (Little Rock AFB).

The third building studied at Little Rock AFB was a 1078 sq ft (98.0 m^2) three-bedroom duplex built in 1958. This single-story frame structure contains 142 sq ft (12.9 m^2) of window area and an infiltration/conduction factor of 7748. Figure 33 shows electrical consumption and norms versus months for this group of 268 thermodynamically equivalent buildings. The same trends are evident in this curve as in the other two for Little Rock AFB: an underprediction during the heating months, and an overprediction during the cooling months.

Analysis of Domestic Hot Water Requirement

Actual consumption for family housing during non-heating and -cooling months was analyzed to determine the effects of the number of occupants in a unit on domestic hot water use. Tables 14 through 16 show the tabulated data for three facilities. To eliminate differences in energy use caused by varying building parameters, only thermodynamically equivalent units were selected.

Table 14 shows data for Little Rock AFB. This facility is totally electric, so the monthly consumption values include energy use for lighting and appliances. Since little heating or cooling was used during April, May, and June, the consumption differences between groups of units having different occupancy should accurately reflect the domestic hot water incremental electrical energy use. As shown in Table 14, the average increase in consumption per unit from two to three and from three to four occupants is 80 to 90 kwh (2.88×10^8 to $3.24 \times 10^8 \text{J}$); for changes from four to five and five to six occupants, the increase is 159 and 137 kwh (5.72×10^8 and $4.93 \times 10^8 \text{J}$), respectively. The norm algorithm, for the hot water heating energy requirements, predicts a constant 145 kwh ($5.22 \times 10^8 \text{J}$) increase per occupant for the average water temperature of 74°F (23.3°C) during this period. This indicates that the domestic hot water norm which allows 25 gallons (94.6 L) of 140°F (60°C) hot water per person will be consistently overstated. Figures 32 and 33 indicate a norm approximately 200 kwh ($7.2 \times 10^8 \text{J}$) higher than actual consumption during April, May, and June.

Table 15 provides data for Cannon AFB. This activity uses natural gas for domestic hot water heating. During the minimal heating months of May, June, July, the data reflect the actual consumption for pilot lights, minimal heating, cooking, and domestic hot water. This table shows that an increase from two to three occupants requires an additional 260 cu ft (7.4 m^3) of natural gas. Larger amounts of energy are used when occupancy changes from three to four occupants (460 cu ft [13 m^3]) and from four to five occupants. The average calculated norm increase per occupant during this time was 620 cu ft (17.6 m^3). Again, heating energy required for the domestic hot water norm will tend to be overstated. This high trend is also shown in Figures 10, 15, and 17, where the norm consumption for low heating degree day months is higher than the mean of actual consumption.

Table 16 shows the natural gas consumption for Fort Gordon, GA, during the nonheating months. The data reflect the actual use for pilots, cooking, and domestic hot water heating. Energy use data do not vary significantly for units hav' ? two to four occupants. However, as occupancy increases from four to five occupants, there is an increase of 450 cu ft (12.7 m^3) in the natural
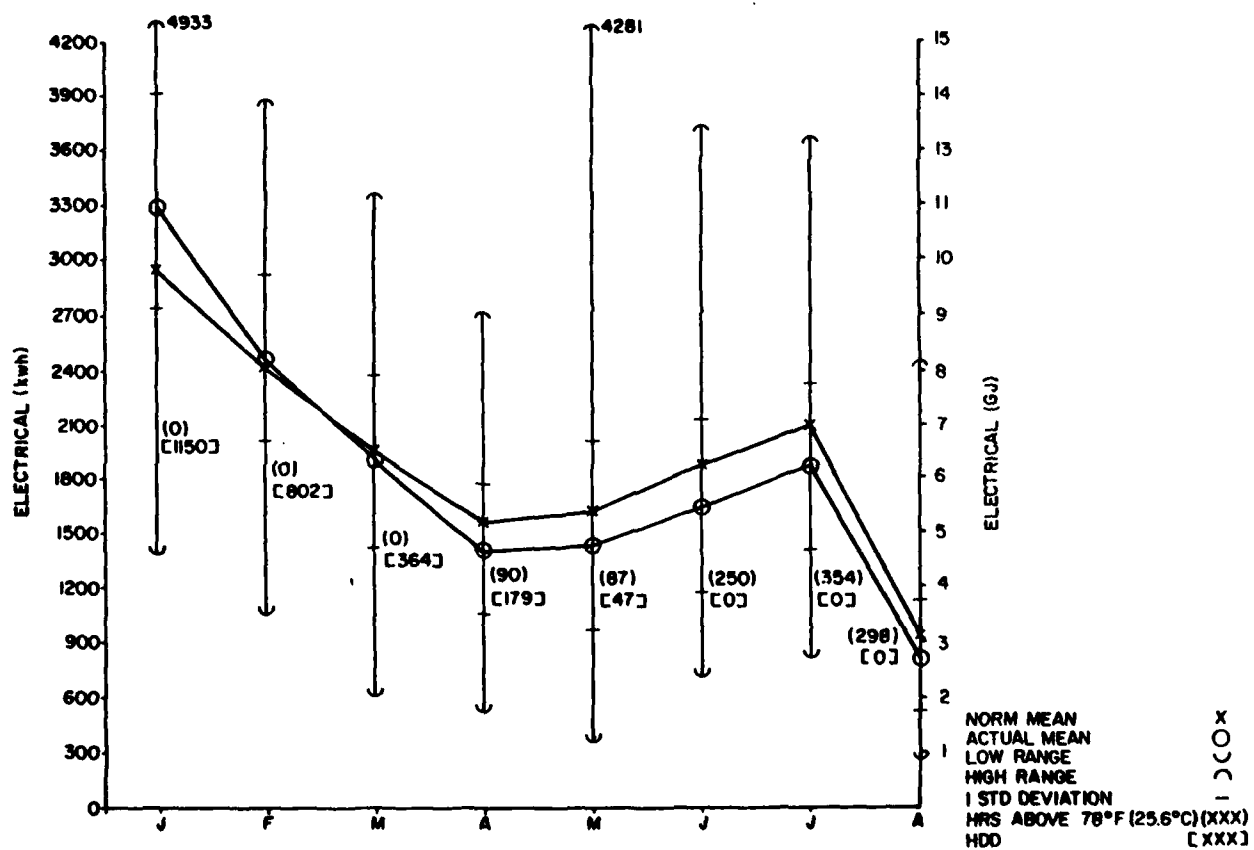
Figure 33. Electrical Consumption and norms versus months (Little Rock AFB).

Table 14

Energy Usage Versus Occupancy: Little Rock AFB

No. of Occ.	Actual Consumption, kwh (GJ)			Average Consumption (kwh) [GJ])	Increase per Occupant	Sample Size
	April	May	June			
2	1200 (4.32)	1178 (4.24)	1314 (4.73)	1230 (4.43)	--	52
3	1247 (4.49)	1265 (4.55)	1446 (5.21)	1319 (4.75)	89 (0.32)	106
4	1314 (4.73)	1347 (4.85)	1536 (5.53)	1399 (5.04)	80 (0.24)	193
5	1470 (5.29)	1546 (5.57)	1658 (5.97)	1558 (5.61)	159 (0.57)	75
6	1571 (5.66)	1677 (6.04)	1838 (6.62)	1695 (6.10)	137 (0.49)	24
4	1571 (5.66)	1677 (6.04)	1836 (6.62)	1695 (6.10)	137 (0.49)	6

Table 15

Energy Usage Versus Occupancy: Cannon AFB

No. of Occ.	Actual Consumption, cu ft x 100 (m^3)			Average Consumption cu ft x 100 (m^3)	Increase per Occupant	Sample Size
	May	June	July			
2	42.3 (120)	33.8 (96)	33.1 (94)	36.4 (103)	--	35
3	47.0 (133)	36.4 (103)	33.5 (95)	39.0 (110)	--	55
4	54.8 (155)	40.1 (114)	36.0 (102)	43.6 (123)	2.6 (7)	48
5	65.9 (187)	46.9 (133)	36.7 (104)	49.8 (141)	6.2 (18)	20

Table 16

Energy Usage Versys Occupancy: Fort Gordon

No. of Occ.	Actual Consumption, cu ft x 100 (m)			Average Consumption, (cu ft x 100 (m^3)	Increase per Occupant	Sample Size
	May	June	July			
2	38.9 (110)	35.4 (100)	35.6 (101)	36.6 (104)	--	17
3	39.3 (111)	35.4 (100)	34.6 (98)	36.4 (103)	--	26
4	38.6 (109	36.2 (103)	35.0 (99)	36.6 (104)	0.2 (1)	24
5	42.0 (119)	39.6 (112)	41.6 (118)	41.1 (116)	4.5 (13)	20
6	47.0 (133)	42.5 (120)	45.5 (129)	45.0 (127)	3.9 (11)	15

gas required. Likewise, as occupancy increases from five to six occupants, the average increase in natural gas consumption is 390 cu ft (11.0 m^3). The calculated average hot water norm for this facility and time period is 540 cu ft (15.3 m^3) per occupant. The calculated norm will therefore reflect an inaccuracy as the number of occupants in a unit increases.

Data Summary

The Port Hueneme data show an electrical norm higher than average actual consumption for two- and three-bedroom units and slightly lower for four-bedroom units. The reasons for the difference in electrical consumption cannot be determined accurately since the average number of occupants in each sample group is equivalent. The four-bedroom units shown in Figure 7 use 100 kwh (3.6 x 10^{8}J) per month more than the duplex units, which have three bedrooms. The actual consumption and norm track well, indicating relatively simple adjustments to the norm could be made to obtain closer agreement. The gas consumption for all three units tracks quite well, indicating that the heating algorithm correctly predicts consumption based on heating degree days. Adjustments to the baseline loads and heating system efficiency, or corrections to the infiltration/conduction factor for the buildings would substantially reduce the variance between the actual mean and the norm. However, the large differences between the minimum and maximum consumption of these thermodynamically equivalent units suggest that wide variations in actual consumption are caused by the habits of occupants.

The Cannon AFB data show that the electrical norm is consistently higher than the actual mean data for identical building groups; this indicates that the DOD projected electrical energy consumption per unit is higher than it should be, even though it contains proper diurnal adjustments. Data tend to indicate a more significant difference between three- and four-bedroom units than between two- and three-bedroom units. Data reveal either that units are being cooled to temperatures lower than 78°F (25.6°C), or that the algorithm used to calculate the norm must be adjusted to predict a building's cooling requirements more accurately. Gas consumption at Cannon AFB is consistently higher than the calculated norm. A refinement of the furnace efficiencies, a sampling of indoor thermostat settings, and a recheck of the calculated infiltration/conduction factor is required to determine the cause of the variance.

The Quantico data show that the electrical norm is lower than actual consumption for the two-bedroom units and higher than actual for the three-bedroom units; this suggests that the "number of bedrooms" electrical norm may be separated incorrectly at the two- and three-bedroom levels. The second data case shown in Figure 21 is assumed to be incorrect from the standpoint of actual consumption data. In all cases, gas consumption is higher than the norm-predicted value; this could happen for a variety of reasons -- one being higher thermostat settings in the units during the heating months. However, the excellent tracking of norm and actual curves indicates that the heating algorithm equation form is correct.

Fort Gordon data showed electric norms higher than actual consumption. Variations in the data were consistent for each building, but it appears the baseline electrical norm is high by about 100 kwh (3.6 x 10^{8}J). The norm

reflected cooling energy requirements before the housing occupants began using their air conditioners. Again, the heating norm was lower than the actual consumption. Since the variation is normally less than 20 percent, simple adjustments to norm parameters could easily eliminate the disparity.

The Little Rock AFB data showed a high norm allowance in the cooling season and a low norm in the heating months. It is suspected that the constant coefficient of performance (COP) selected for the heat pump is the major problem at this installation. The COP probably should be lower in the heating mode and higher in the cooling mode. Though further research is required, a simple seasonal adjustment would create a good agreement both in the heating and cooling seasons.

Variables in Norm Development

The heating and cooling loads in family housing depend on the interrelationship of many variables. Among these are outdoor temperature, indoor thermostat setting, insulation levels of the walls, roof, and floor, amount of window area, amount of outdoor air leakage, amount and use of lights and appliances, heating and cooling system efficiencies, and the number and lifestyle of occupants.

The indoor setpoint temperature (the actual thermostat setting) within the military family housing unit cannot be controlled for purposes of improving the norm algorithm prediction accuracy. The norms were developed by using a constant 68°F (20°C) indoor setpoint for heating and a 78°F (25.6°C) setpoint for cooling. Variations from the modeled thermostat setpoints in the actual units would change the amount of energy used for heating and cooling. It is common knowledge that a 1°F difference in the heating thermostat setpoint can increase heating energy use up to 5 percent; a 1°F variation in cooling thermostat setpoint can increase cooling energy requirements up to 10 percent.

The insulation levels of the walls, roof, and floor and the amount of air leakage in the building were accounted for in the norm by the infiltration/conduction factor (calculated for each family housing unit in the test metering program). The calculation was very important; for example, a 5 percent error in calculating this factor would produce a corresponding 5 percent variation in the norm calculation. Training and instructions were provided to the survey teams for determining this important parameter. However, in the early stages of the program, several calculation errors were found; the significant errors resulted from improper selection of material U values and were corrected. However, a system of additional checks during calculation should be incorporated to ensure accuracy.

The heating and cooling system efficiencies selected for the test metering program appear to be rather stringent. (A higher than actual efficiency will cause the calculated norm to be low.) For this test program, a constant annual efficiency, based on the type of system used in the family housing unit, was selected for heating and cooling systems. The curves obtained from this study show that the efficiencies change based on the amount of system use. For example, Figure 4 shows that the variance between the norm and actual consumption is wider in the lower heating degree months than in the

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higher heating degree months. This indicates a higher efficiency during severe heating months and a lower efficiency during milder months. Further analysis of the actual data and more research into family housing system efficiencies are required to completely define the seasonal variations of family housing system efficiencies -- variations which the algorithm should take into account to provide more accurate norm prediction.

The lifestyle of occupants remains the most unpredictable parameter in the norm development. Tables 14 and 16 showed that the increase in energy use among thermodynamically equivalent units with different occupancies is not consistent. The curves indicate wide variations between the minimum and maximum consumption in thermodynamically equivalent units. Refinements of the norm algorithm will allow better prediction of electrical, domestic hot water, and heating and cooling energy requirements; however, actual use will still fluctuate widely because energy requirements vary with the habits of the occupants.

5 CONCLUSIONS

This report has documented the development and testing of a procedure establishing energy consumption norms for family housing units.

While heating and cooling requirements can be determined with the norm concepts and algorithms described, the present norm tends to overpredict electrical requirements and underpredict heating and cooling requirements. With refinements, these requirements can be determined to an accuracy of about 5 percent; however, there will still be wide fluctuations in actual use due to varying lifestyles and corresponding different uses of energy. The excellent tracking of the norm with actual consumption shows that the weather parameters used in the norm algorithm properly predict trends in heating and cooling requirements (Figure 16). The analysis of energy usage versus occupancy indicates the hot water norm is high for family housing units with a large number of occupants. Energy usage for domestic hot water between two and three occupants does not substantially increase. The incremental increase in energy usage per occupant due to domestic hot water is larger for occupancies above four, indicating that a linear relationship between water usage and number of occupants does not exist (Tables 14 through 16). These tendencies suggest that fluctuations in domestic hot water consumption are more likely due to differences in occupant lifestyle than number of occupants.

The test metering program and analysis of actual data indicated refinements of the algorithms are needed if DOD implements an excess billing program. Among these refinements are (1) investigations of residential heating system efficiency and its variation with outside air temperature, and of cooling system COP and its variation with cooling requirements; (2) a requirement for detailed training procedures for personnel who will be grouping thermodynamically equivalent housing units and calculating infiltration/conduction factors; (3) a revised method to predict electrical requirements more accurately than by number of bedrooms; (4) refinement of fan energy requirements; and (5) refinement of domestic hot water heating requirements.

APPENDIX:

FAMILY HOUSING SURVEY

Building Number* _____.

Building Group Number _____.

Installation _____.

If Building is:

Group 3, fill out basic form (minus question 18) and fill out all required supplemental sheets.

Group 2, give building number of group 3 building which most closely typifies this building _____.

Type of dwelling: _____

Type of construction: _____

and fill out questions 1 through 18 of basic form, including the calculation sheet for question 18.

Group 1, give building number of group 2 building which this building is identical to: _____. And fill out questions 1-17 of basic form.

*(one set of data is required for each family unit).

BASIC BUILDING SURVEY DATA

1. Installation: _____

2. Activity Identifier Code: [ ][ ][ ][ ][ ][ ]

3. Building Number: [ ][ ][ ][ ][ ][ ]

4. Account Number: [ ][ ][ ][ ][ ][ ]

5. Address: [ ]

6. Number of Occupants: [ ][ ]

7. Number of Bedrooms: [ ]

8. Floor Area: [ ][ ][ ][ ]

9. Building Volume: [ ][ ][ ][ ][ ]

10. Window Area: [ ][ ][ ]

11. Domestic Water Heater Fuel: [ ]
    (G = Gas, E = Elect, O = Oil,
    S = Steam, H = Hot Water)

12. Cooking Fuel: [ ]
    (G = Gas, E = Elect)

13. Pilot Lights: (indicate number of Pilots, 0-9)

    a. Domestic Water Heater: [ ]

    b. Range: [ ]

    c. Clothes Dryer: [ ]

    d. Furnace: [ ]

    e. Air Conditioner: [ ]

14. Heating Systems:

    a. Fuel: (G = Gas, E = Elect, O = Oil, S = Steam, H = Hot Water) [ ]

    b. Type: Forced Air _____, Baseboard _____, Convector _____, Radiator _____

    c. Output Capacity: _____ Btu/hr

    d. Age: _____ Years

15. Cooling System:

    a. Fuel: (G = Gas, E = Elect, O = Oil, S = Steam, H = Hot Water, [ ]
        C = Chilled Water)

    b. Type: Central Air _____, Window Units _____, Evaporative Cooling _____

    c. Number of Units: _____

    d. Capacity and Age of Each Unit:

        1) _____ Btu/hr _____ Years

        2) _____ _____ Years

        3) _____ _____ Years

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Activity Identifier Code ☐☐☐☐☐☐
5   8

Building Number ☐☐☐☐☐☐
9   14

Account Number ☐☐☐☐☐☐
15   20

6. List all common energy consuming devices outside the dwelling which are to be billed to the occupant and estimate their daily consumption.

a. Electrical (KWH)   b. Gas (Btu's)

Total ☐☐☐   Total ☐☐☐☐☐☐
       21   23   24   29

c. Oil (Btu's)   d. Steam (Btu's)

Total ☐☐☐☐☐☐   Total ☐☐☐☐☐☐
      30   35   36   41

e. Hot Water (Btu's)   f. Chilled Water (Btu's)

Total ☐☐☐☐☐☐   Total ☐☐☐☐☐☐
      42   47   48   53

7. General Building Description:

a. Construction Type: ☐
   (C = Precast Concrete, F = Frame, B = Brick/Block, M = Masonry,   54
   O = Brick/Frame, S = Steel

b. Year structure was built: ☐☐
                                                              55   56

c. Has building been weatherstripped and caulked: (Y = Yes, N = No) ☐
                                                                    57

d. Does structure have storm windows/doors: (Y = Yes, N = No) ☐
                                                              58

e. Type of Dwelling: ☐
   (S = Single Family, D = Duplex, T = Townhouse, O = Other [Specify]) 59

f. If more than two family, is unit: ☐
   (E = End Unit, C = Center Unit)   60

g. Is unit (T = top floor, M = middle floor,   ☐
   L = lowest floor)   61

h. Number of stories   ☐
                                                              62

i. Indicate basement, crawl space, or slab: ☐
   (B = Basement, C = Crawl space, S = Slab)   63

j. Is there an attic: (Y = Yes, N = No)   ☐
                                                              64

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18. Calculation of U-factor/Infiltration constant (A) U-factor (use attached calculation sheet).

a. Identify all thermodynamically unique sections of the external shell except surfaces in contact with the earth.

Example: Walls: All external walls differing composition.

Roof: All roof sections of differing composition.
(not considered if building has ventilated attic).

Windows: All areas of differing composition.

Doors: All different constructions of doors.

Floors: All floor sections of different composition elevated above grade (exposed to outside air).

Ceiling: All ceiling sections of different composition-below unheated/cooled space (exposed to outside air).

b. Calculate the area (ft^2) of each unique section of the external shell.

c. For each unique section, calculate the total thermal resistance as follows:

$$R_{total} = R_{outside \ film} + R_1 + R_2 + \ldots + R_{outside \ film}$$

(Values for R_1, R_2, can be obtained from ASHRAE Handbook of Fundamentals, Chapter 20. Use .68 for $R_{inside \ film}$ and .17 for $R_{outside \ film}$.

d. Calculate the "U" factor for each unique section: $U = \dfrac{1}{R_{total}}$.

e. For each unique section multiply the U-factor of that section by the area of that section.

f. Sum the UA products of every unique section comprising the external shell of the structure.

g. Calculate the air change rate:

$$ACR = \left[.59 + (.044) \ (\% \ WA) - \frac{(\% \ WA)^2}{3375} \right] (f_s) \ (f_w)$$

Where: % WA = total window area divided by total wall area times 100.
f_s = .82 with storm doors and storm windows, 1.0 otherwise.
f_w = .82 with weatherstripping and caulking, 1.0 otherwise.

h. Calculate A:
A = 24 (UA) + (.432) (ACR) (VOL) _____.

18. (cont'd)   UA Calculation Sheet

SECTION 1	MATERIALS	R VALUES	U = 1/R tot	AREA	U X A
WALL 1					
WALL 2					
WALL 3					
WALL 4					
FLOOR					
ROOF/CEILING					
DOORS					
WINDOWS					
OTHER					

Sum of U X A = _____
(UA)

19. DETAILED BUILDING DESCRIPTION

    a. Sketch Floor Plan, Show Exterior Walls and Dimensions
    (Show True North On Plan)

19. DETAILED BUILDING DESCRIPTION (CONTINUED)

b. Determine length of interior partitions or show partitions and dimensions on floor plan _____

c. Describe construction of interior partitions:

d. Number each exterior wall starting with most north facing and going clockwise around floor plan.

e. For each exterior wall, fill out a wall sheet.

f. Fill out ceiling/roof

g. Fill our a floor description sheet(s) for each floor.*

h. Provide a Polaroid photograph of the buildings front and side elevations.

_____

*The floor/ceiling between floor in Multi-Story Homes is considered a floor.

EXTERIOR WALL DESCRIPTION

a. Installation

b. Building No.

c. Wall No.

d. Sketch and dimension elevations of each wall (looking from exterior).
Show location and number of windows and doors. Show shading devices used
on windows and their dimension (include distance out from wall). Show
entire wall from basement to roof and indicate where types of construc-
tion changes.

e. What type space is outside wall ☐ Earth ___ FT up Wall
☐ Outside ☐ Another living space ☐ Other _____ .

f. Detail Wall Description

Describe wall construction by layers starting with outside layer and working inward using materials from Table 3 and showing thickness of each layer.* Repeat for each construction type used in wall.

LAYER   MATERIAL   THICKNESS (in.)

g. Number windows and describe construction using description from Table 1.

WINDOW   DESCRIPTION   FRAME MATERIAL

*For multimaterial layers such as studs without insulation, air space would be used.

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h. Number doors and describe construction using description from
Table 2.

DOOR   DESCRIPTION

FLOOR DESCRIPTION

a. Installation:

b. Building No.

c. What is under floor ☐ Living Space   ☐ Ground

☐ Crawl Space   ☐ Basement   ☐ Other _____ .

If floor covers two of above, do separate descriptions for each section,

show section on floor plan.

d. If basement is conditioned, then basement floor and walls must be

described using appropriate wall description and a floor description.

e. Describe floor construction by layers starting with outside layer

and working inward using materials from Table 3 and showing thickness.

LAYER   #   MATERIAL   THICKNESS (IN.)

ROOF/CEILING DESCRIPTION

a. Installation:

b. Building:

c. Describe ceiling construction by layers starting with outside layer and working inward using material from Table 3 and showing thickness.

LAYER   #   MATERIAL   THICKNESS (IN.)

d. What is above ceiling? ☐ OUTSIDE   ☐ ATTIC

☐ LIVING SPACE   ☐ OTHER _____ .

e. If attic is checked, fill in attic/roof description sheet.

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